W1036-03

The application was originally made under the Patent Cooperation Treaty with the Japanese Patent Office acting as the receiving office on (86) 15 Oct 1982, being given an application number PCT/JP82/00411. The application was searched by the Japanese Patent Office acting as the International Search Authority (ISA), and published by the International Bureau on (87) 28 Apr 1983 under serial number WO 83/01463 in the Japanese language. The text of the application is contained in the publication made by the International Bureau as above identified, the accompanying text being an English translation thereof.

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(43) Date of issue
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C7A 713 B249 B25X B25Y B289 B309 B310 B316 B31Y B32Y B331 B333 B335 B337 B339 B33X B349 B35Y B361 B363 B365 B367 B369 B36X B370 B375 B377 B379 B37Y B381 B383 B385 B387 B389 B38X B399 B406 B407 B409 B40Y B411 B413 B415 B417 B419 B41X B422 B424 B425 B427 B429 B42Y B431 B433 B435 B437 B439 B43X B440 B449 B44Y B451 B453 B45X B489 B500 B509 B50Y B511 B513 B515 B517 B519 B51X B528 B52Y B531 B533 B535 B537 B539 B53X B545 B546 B547 B548 B549 B54X B54Y B555 B556 B557 B558 B559 B55X B55Y B610 B613 B616 B617 B619 B620 B621 B622 B624 B627 B62X B62Y B630 B633 B635 B636 B661 B663 B665 B667 B669 B66X B670
U1S 2033 C7A
(56) Documents cited by ISA
JP, A, 55-82756
JP, A, 56/98445
(58) Field of search by ISA
INT Cl C22C 21/00, C22C 21/02, F16C 33/12

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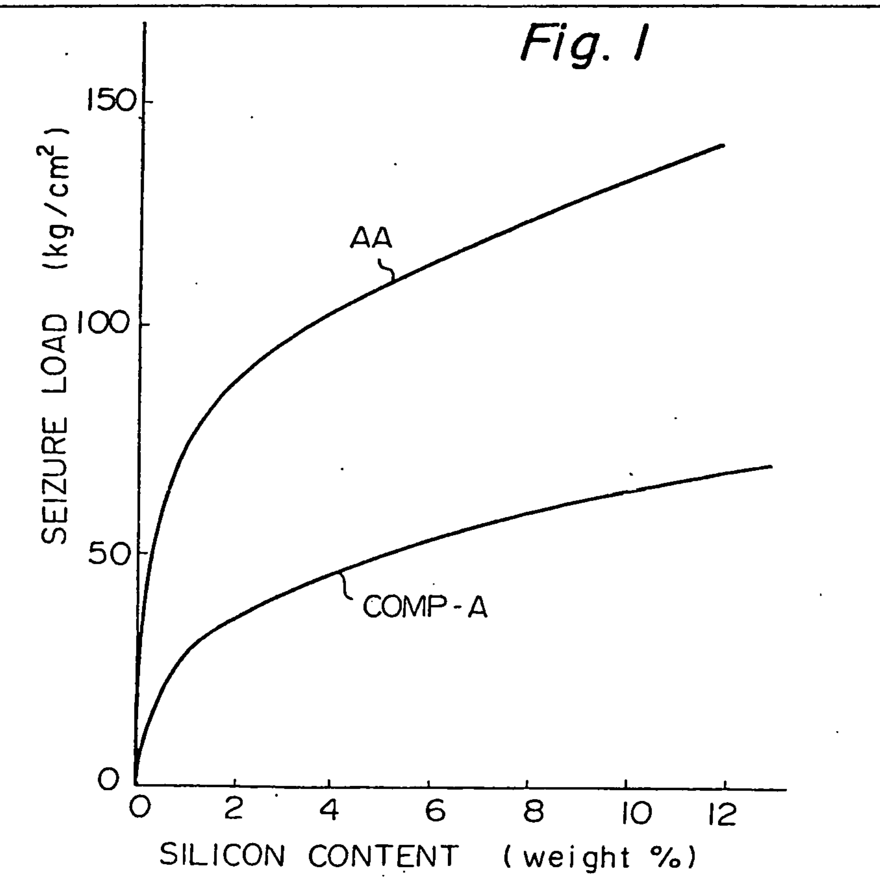
(54) Aluminum alloy bearing

(57) An improved aluminum alloy bearing for use in an internal combustion engine, in which an alloy containing 0.5 to 11% of at least one hard element selected from the group consisting of silicon, manganese, iron, zirconium, titanium, antimony, nickel, molybdenum, cobalt, chromium, and niobium as a necessary component, (a) 0.1 to 10% of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth, (b) 1 to 35% tin, (c) 0.1 to 2% of at least one element selected from the group consisting of copper and magnesium as optical components, and the balance comprising substantially aluminum is bound to a back metal, with 5 or more particles comprising or containing the hard element having a length of 5μ to 40μ existing per $3.56 \times 10^{-2}mm^2$ in any portion of the alloy. This bearing has remarkably improved adaptability to, for example, steel-made crankshaft and seizure load.

Fig. 1



GB 2 121 435 A

Fig. 1

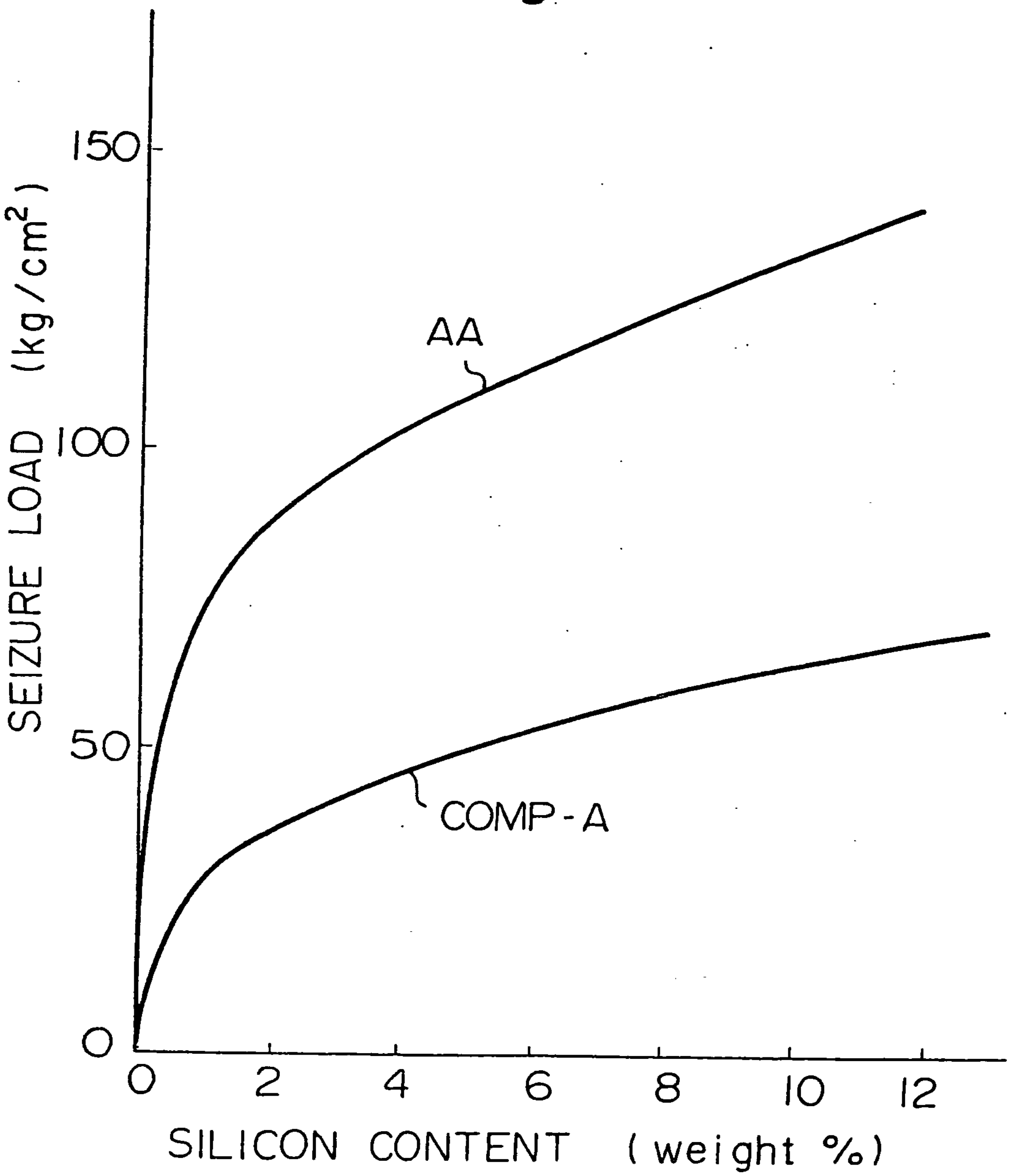

SEIZURE LOAD (kg/cm²)
150
100
50
0
AA
COMP-A
0 2 4 6 8 10 12
SILICON CONTENT (weight %)

Fig. 2

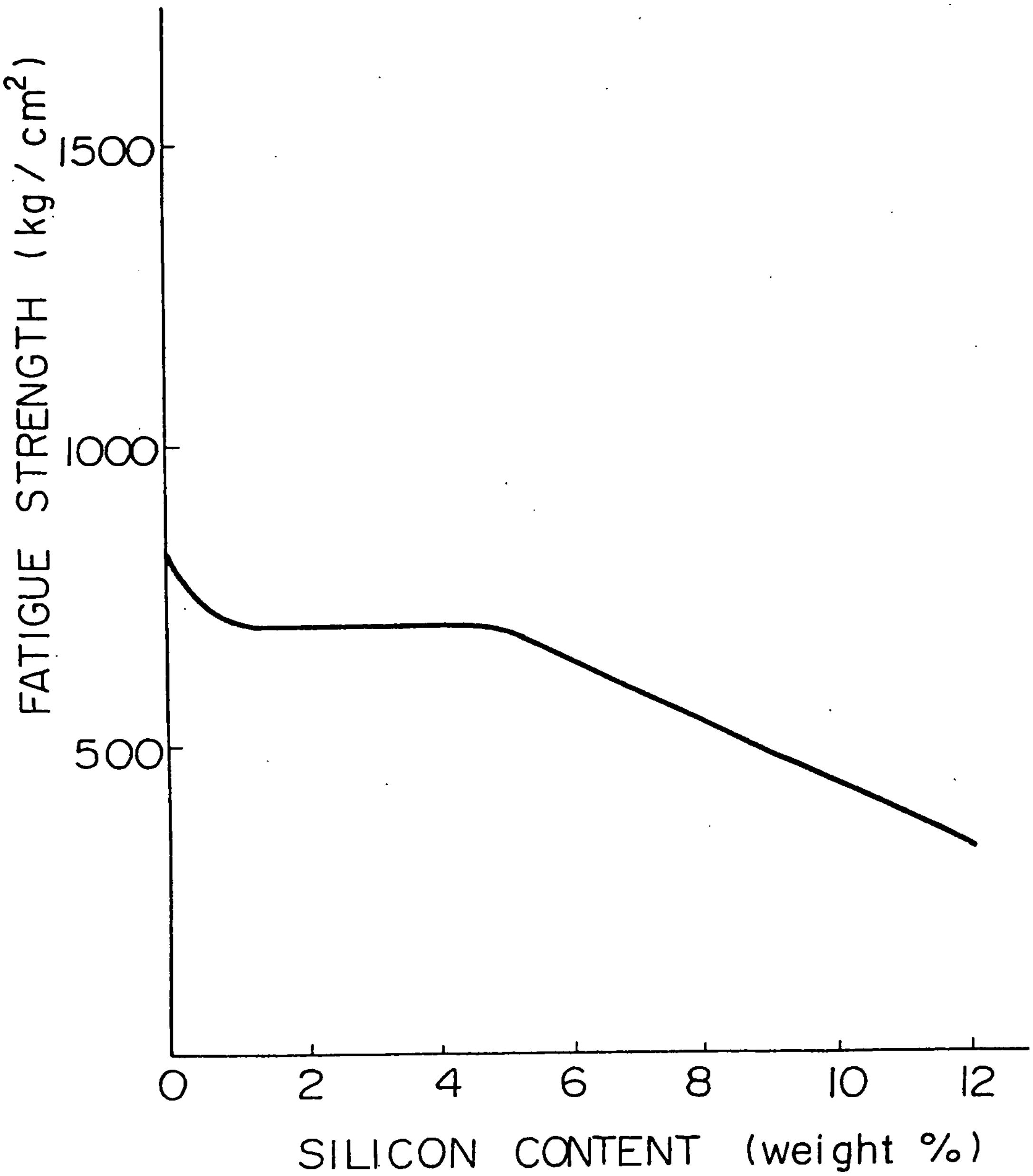

FATIGUE STRENGTH (kg/cm²)
1500
1000
500
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 3

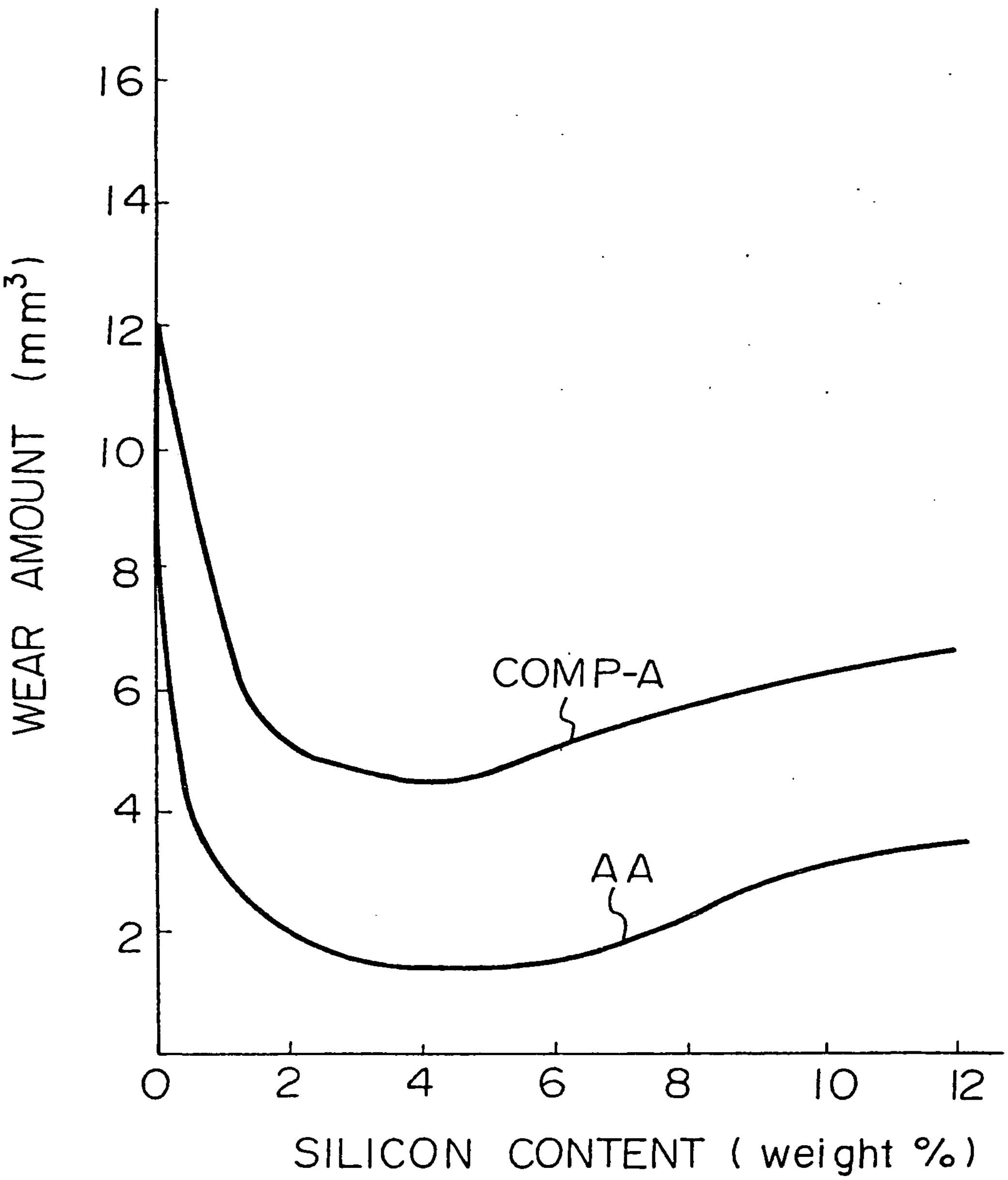

16
14
12
10
8
6
4
2
WEAR AMOUNT (mm³)
COMP-A
AA
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 4

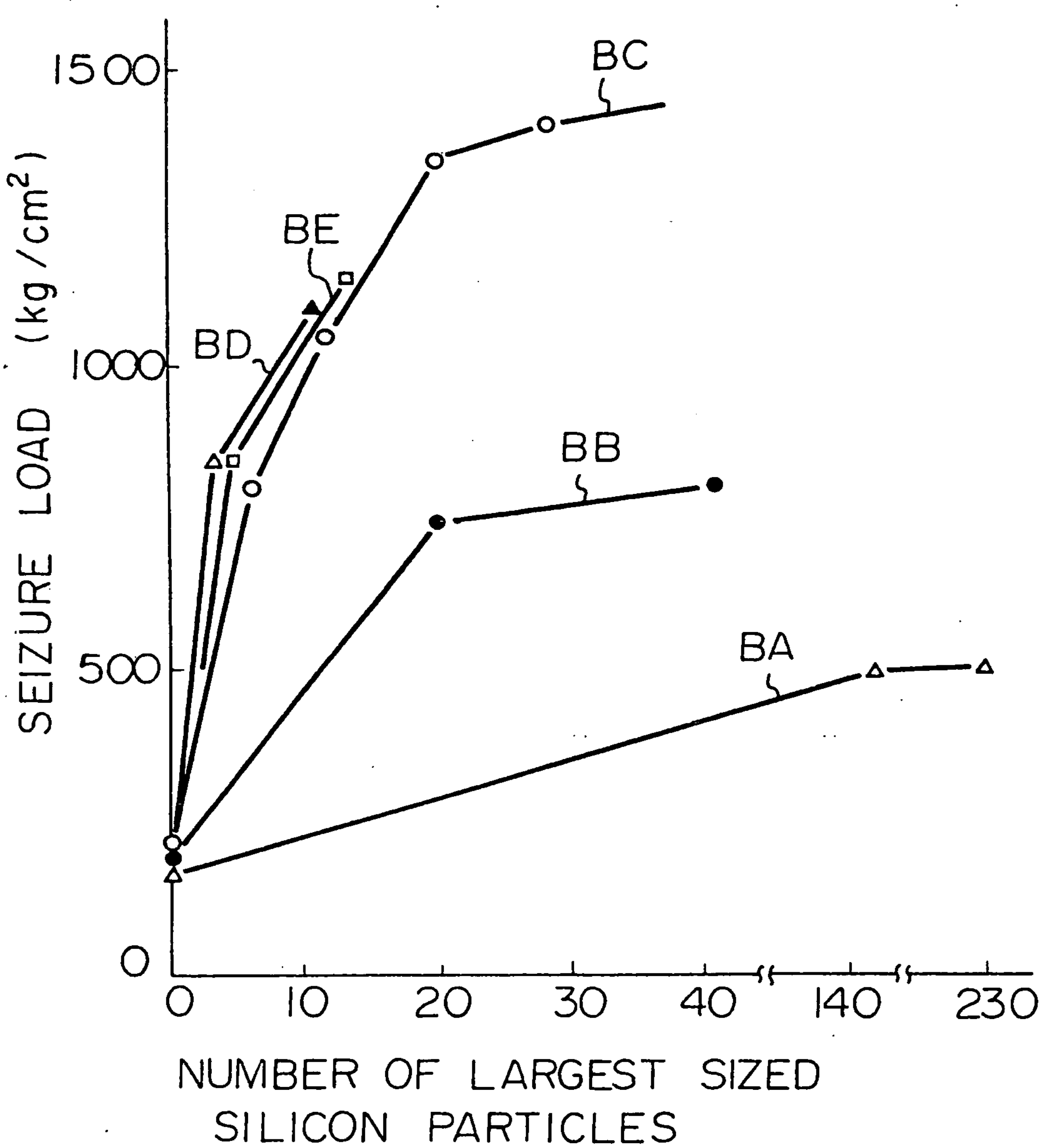
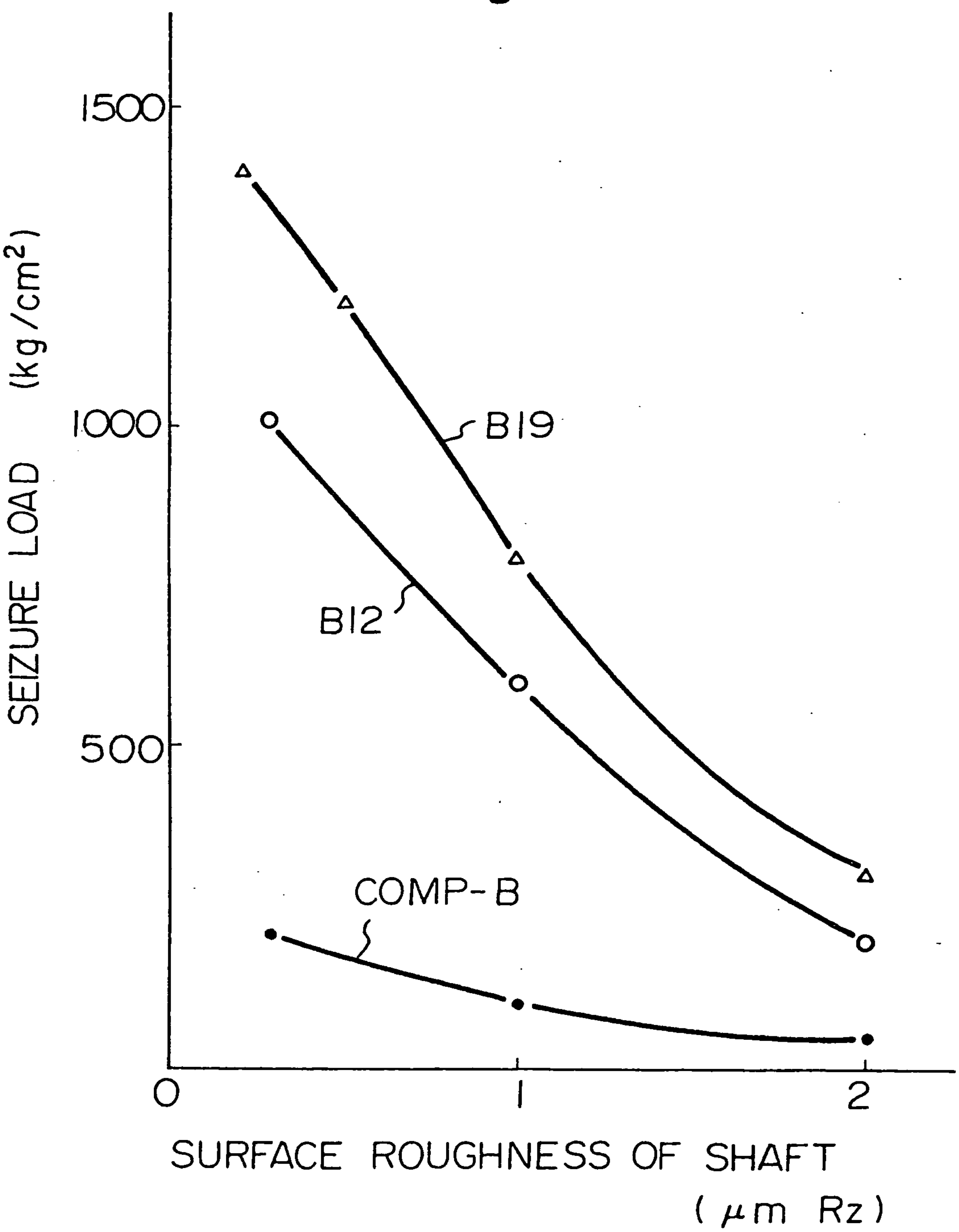
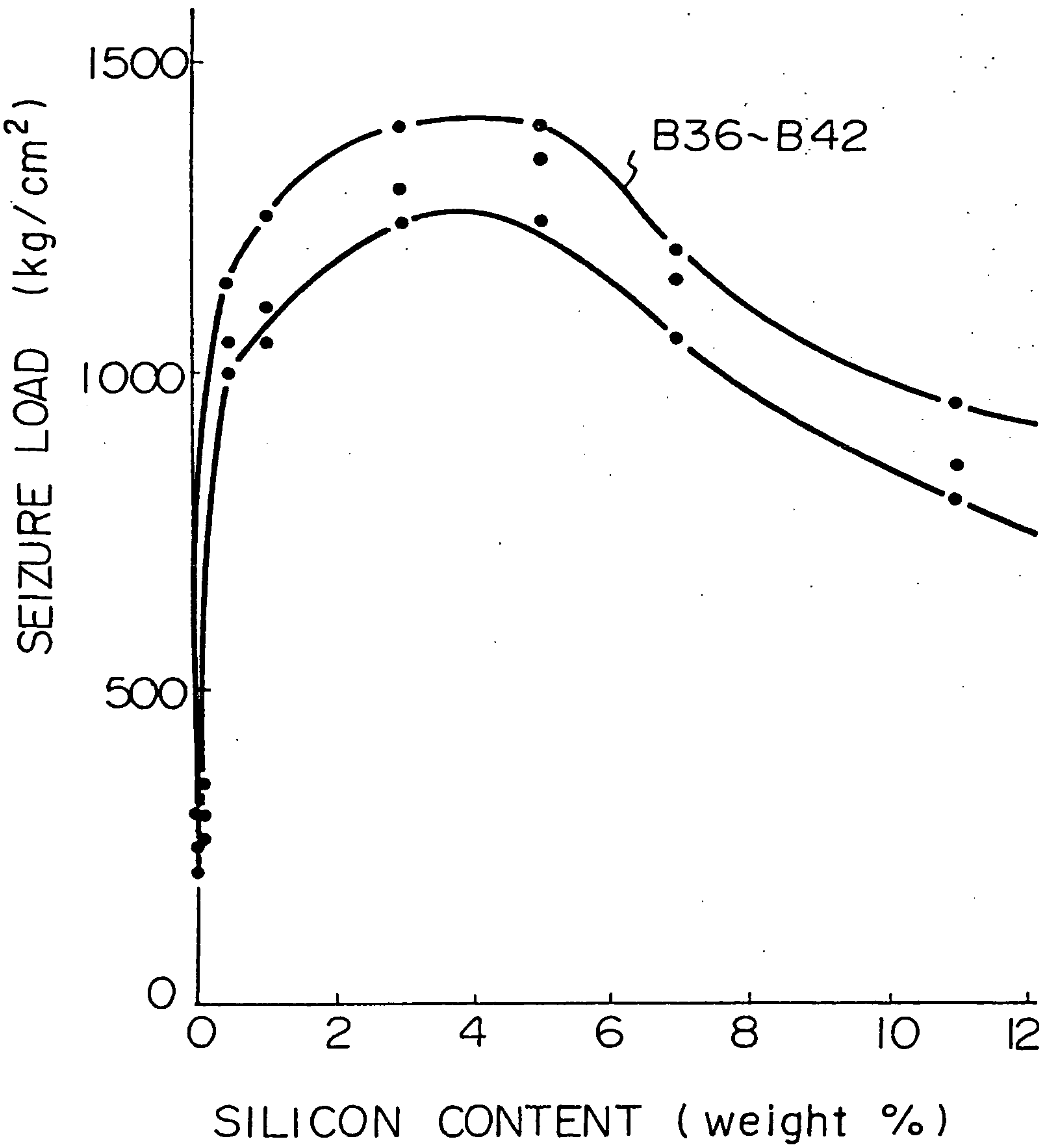

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
BC
BE
BD
BB
BA
0
10
20
30
40
140
230
NUMBER OF LARGEST SIZED
SILICON PARTICLES

Fig. 5



1500
1000
500
SEIZURE LOAD (kg/cm²)
B19
B12
COMP-B
0
1
2
SURFACE ROUGHNESS OF SHAFT
(μm Rz)

Fig. 6



B36~B42
SEIZURE LOAD (kg/cm²)
1500
1000
500
0
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 7

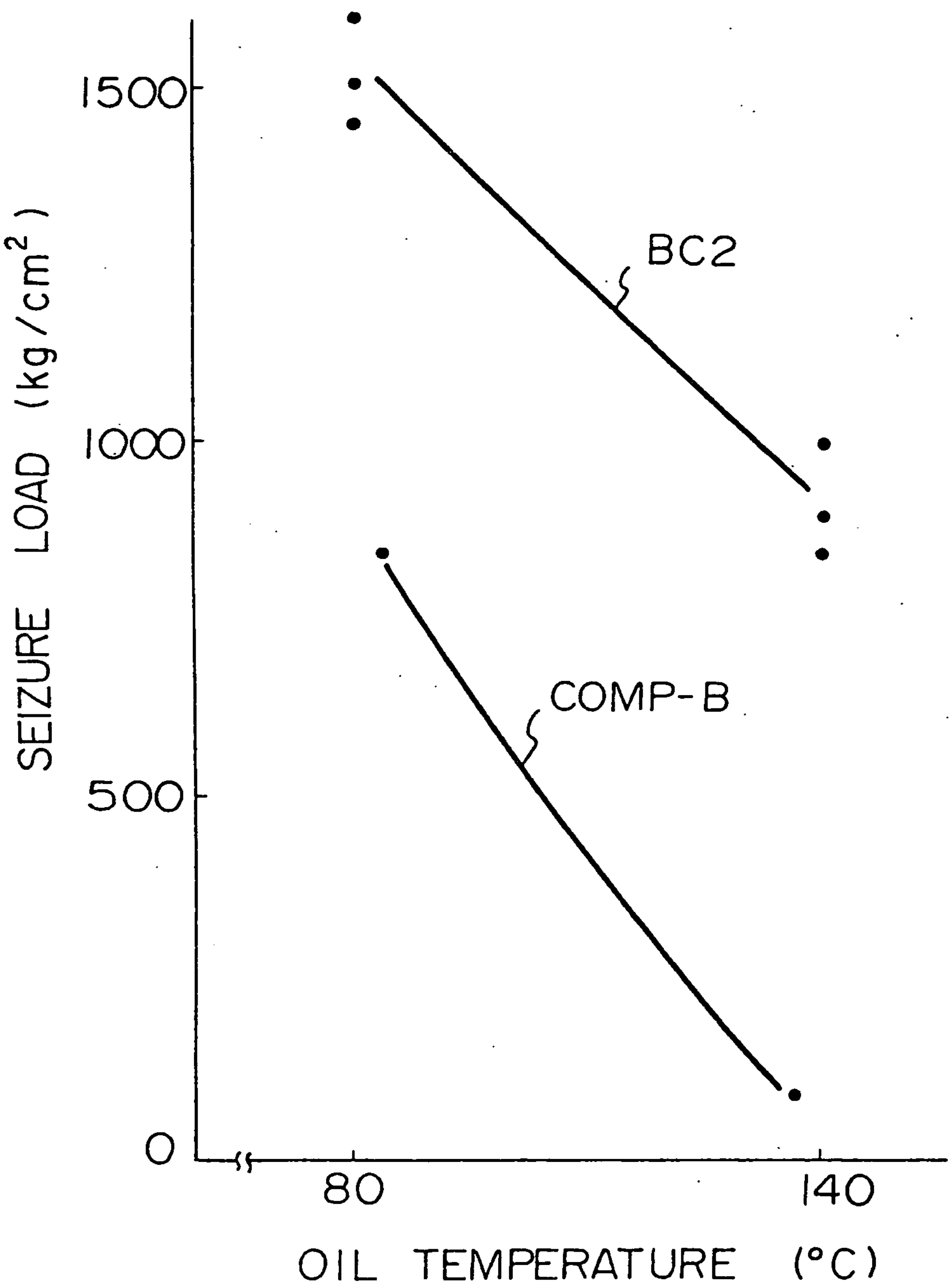

1500
1000
500
0
SEIZURE LOAD (kg/cm²)
BC2
COMP-B
80
140
OIL TEMPERATURE (°C)

Fig. 8

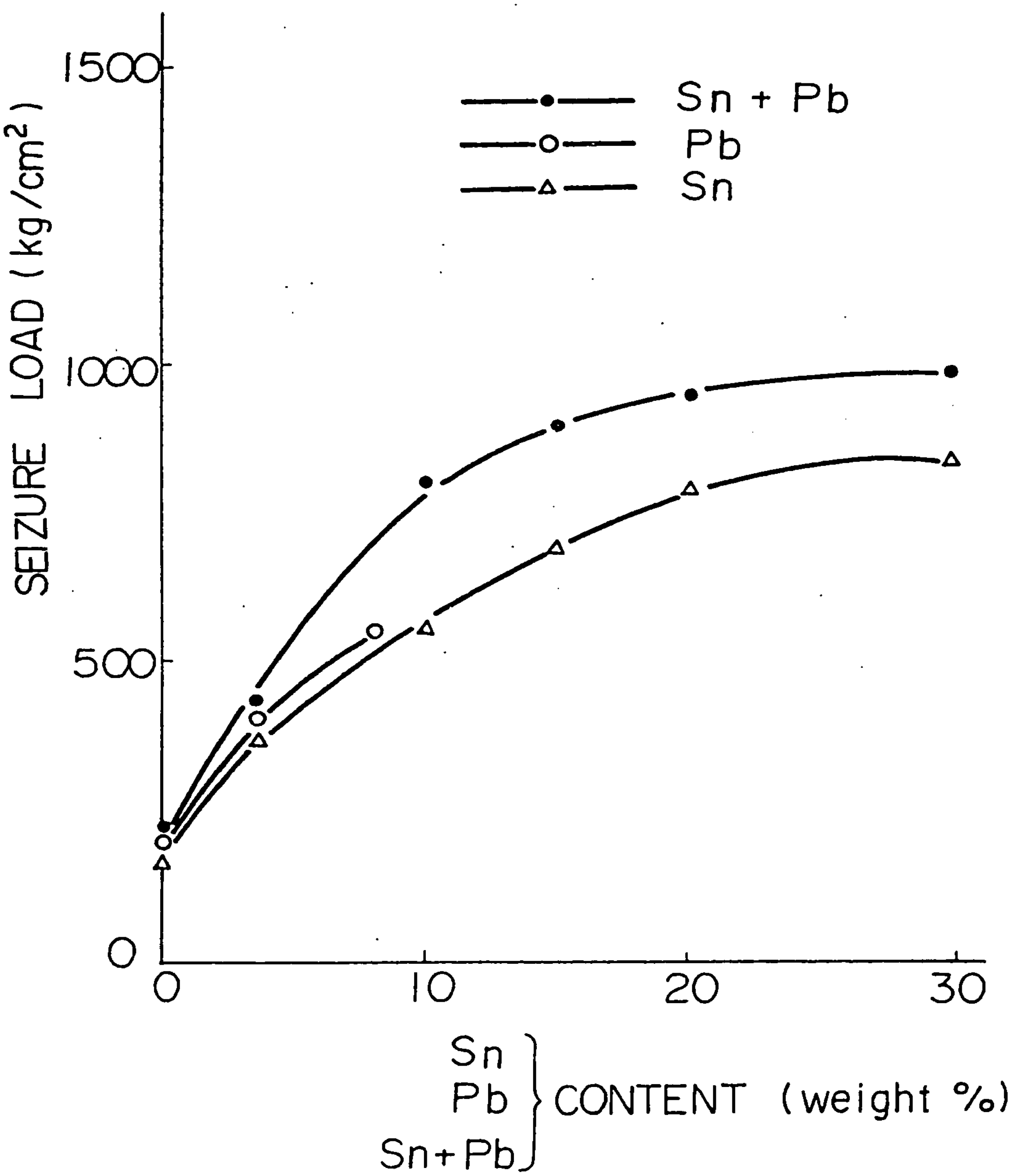

1500
1000
500
0
SEIZURE LOAD (kg/cm²)
Sn + Pb
Pb
Sn
0
10
20
30
Sn
Pb
Sn+Pb
CONTENT (weight %)

Fig. 9

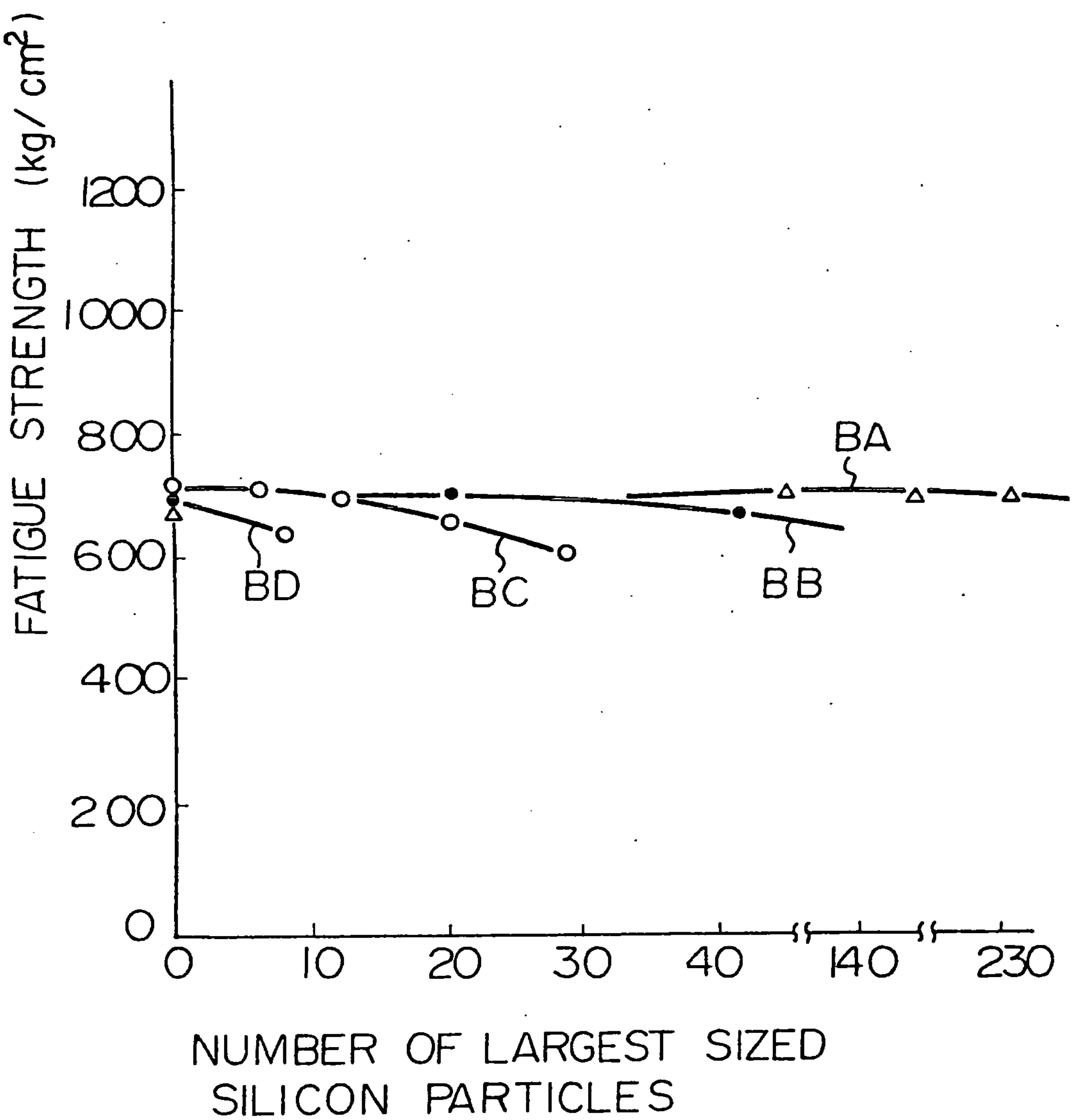

FATIGUE STRENGTH (kg/cm^2)
1200
1000
800
600
400
200
0
BA
BB
BC
BD
0
10
20
30
40
140
230
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 10

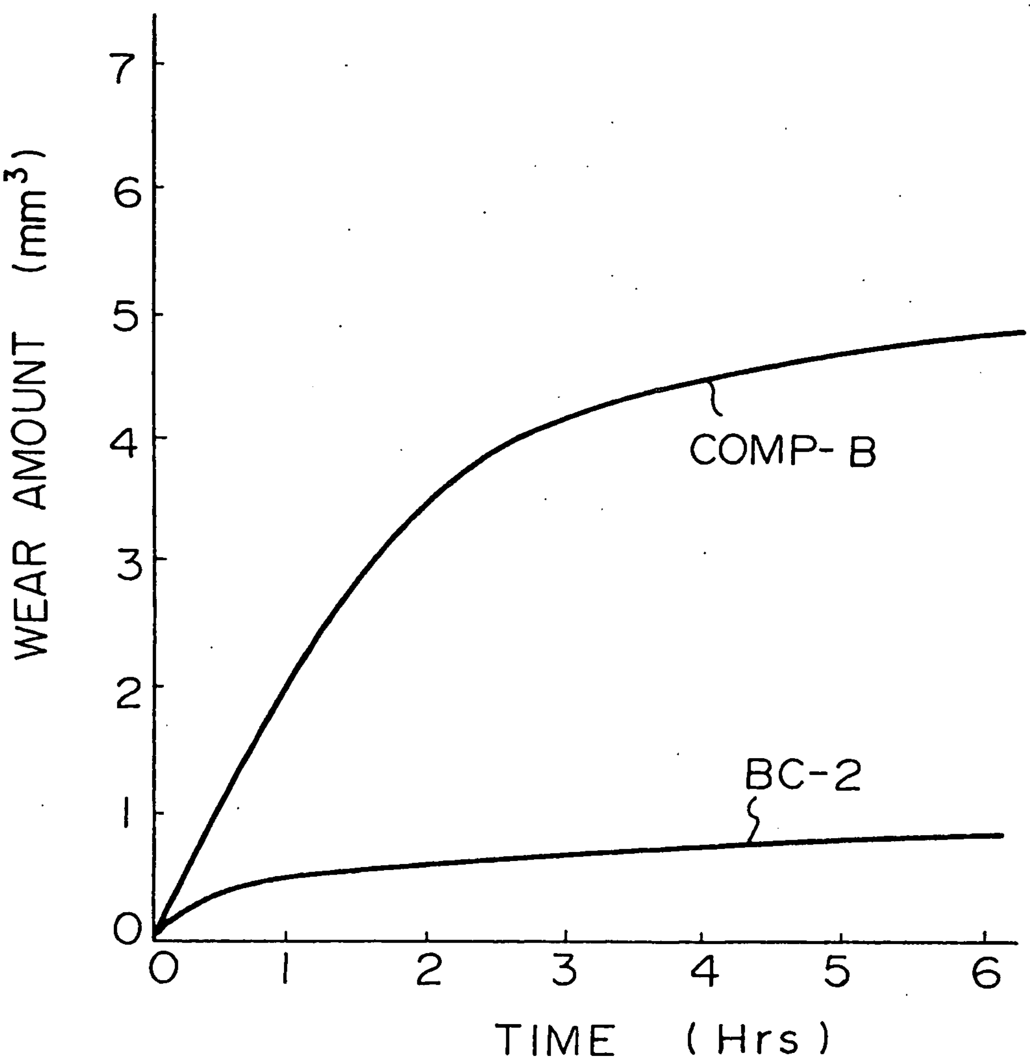
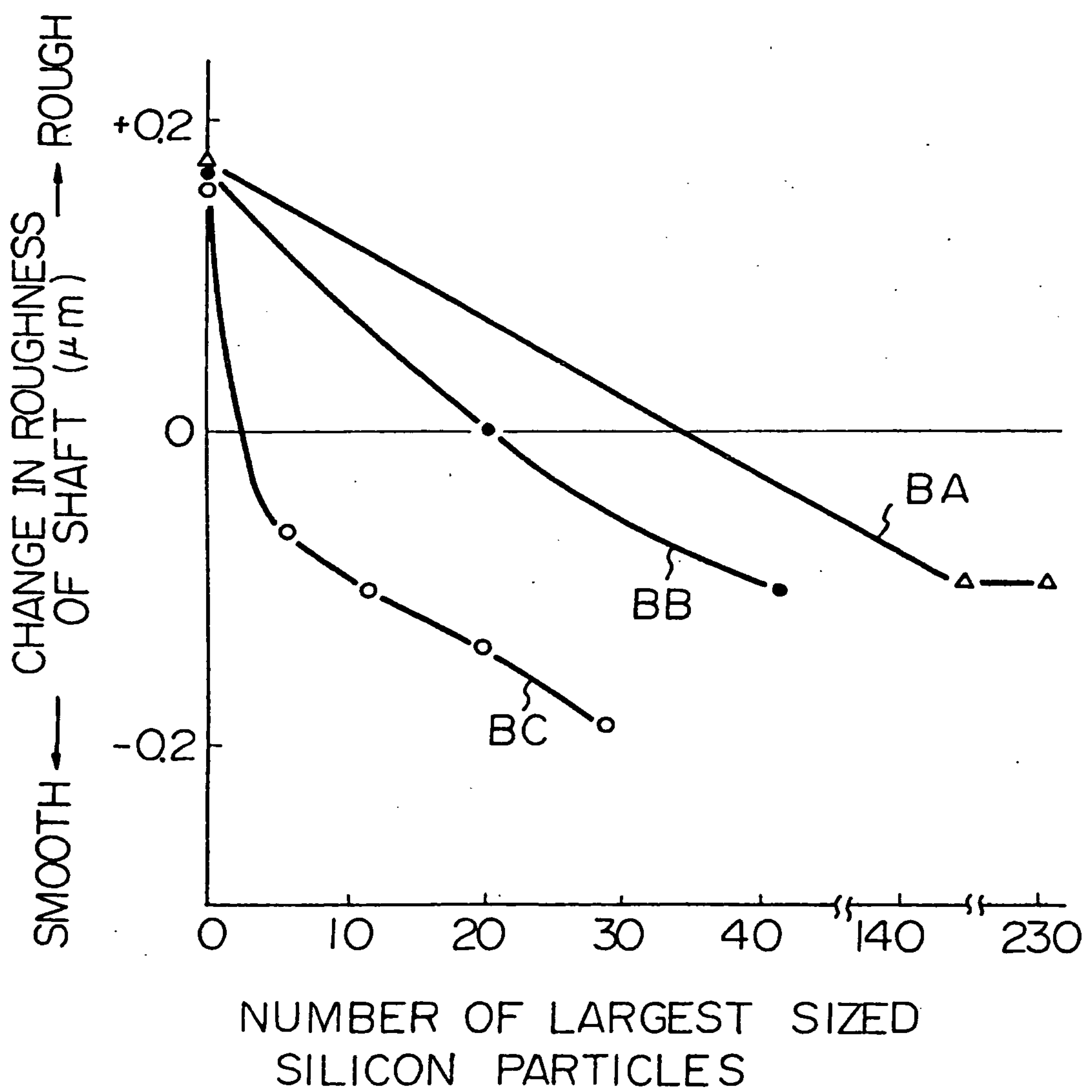


Fig.11



SMOOTH ← CHANGE IN ROUGHNESS OF SHAFT (μm) → ROUGH
+0.2
0
-0.2
BA
BB
BC
0
10
20
30
40
140
230
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 12

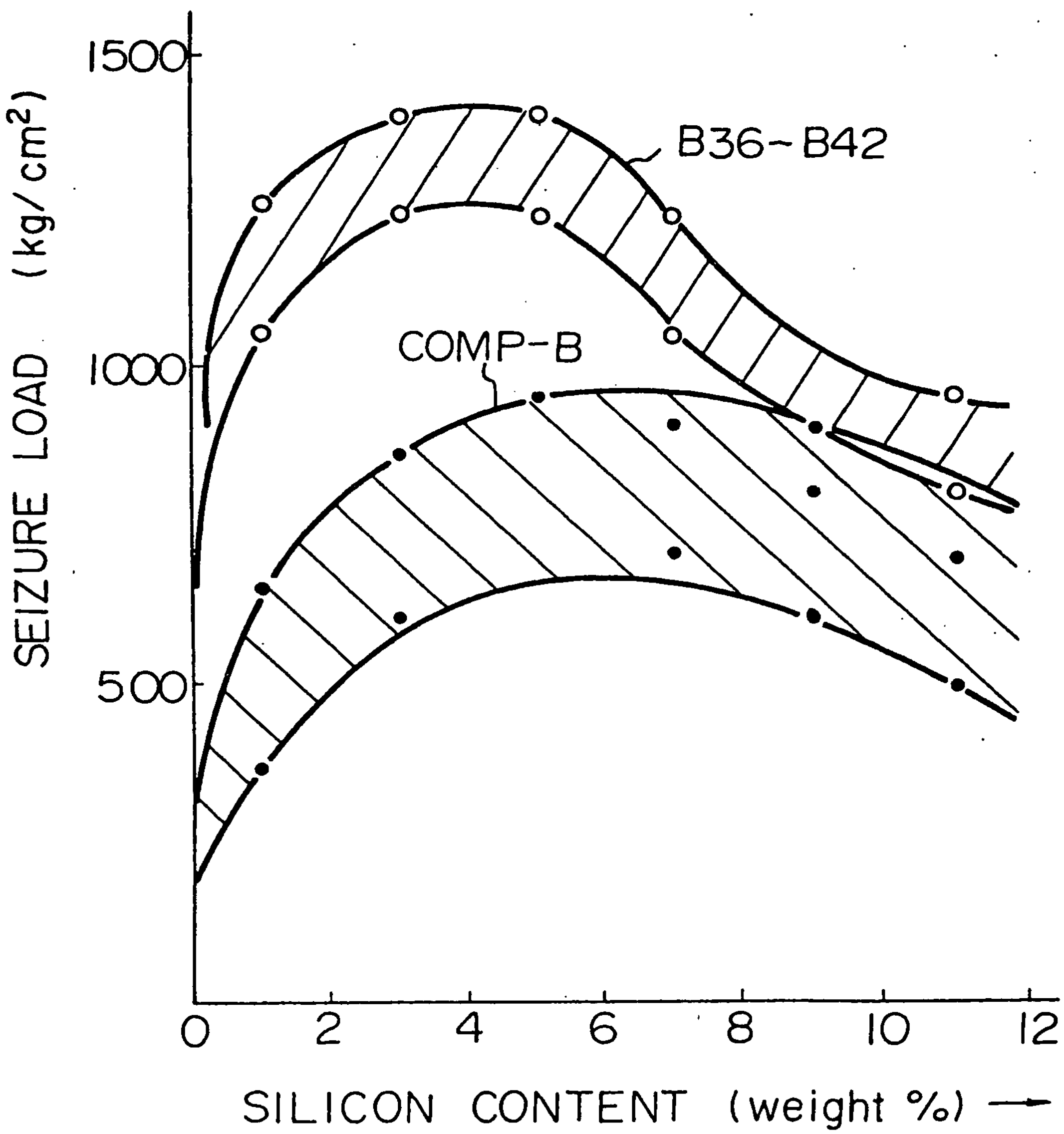

B36~B42
COMP-B
SEIZURE LOAD (kg/cm²)
1500
1000
500
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 13

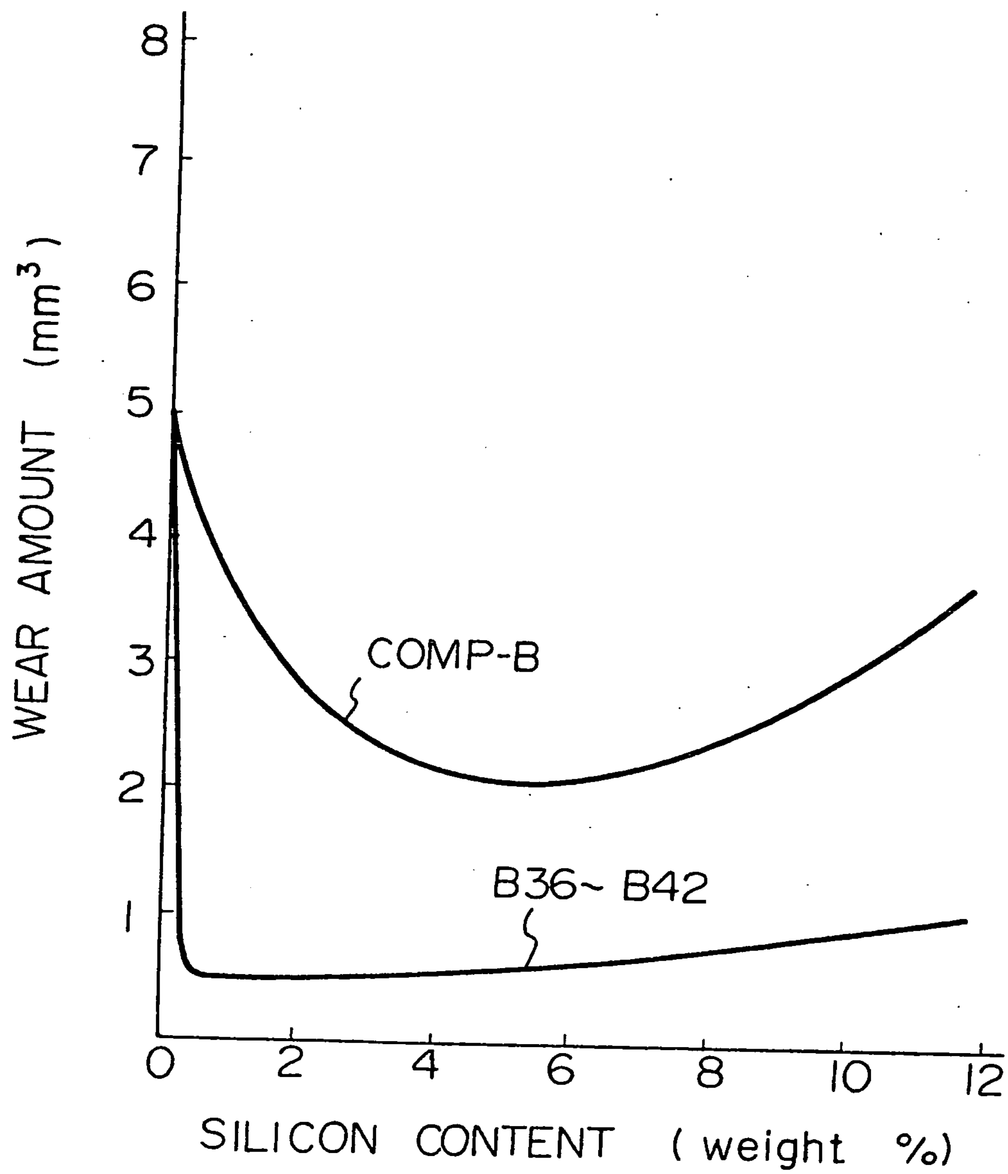
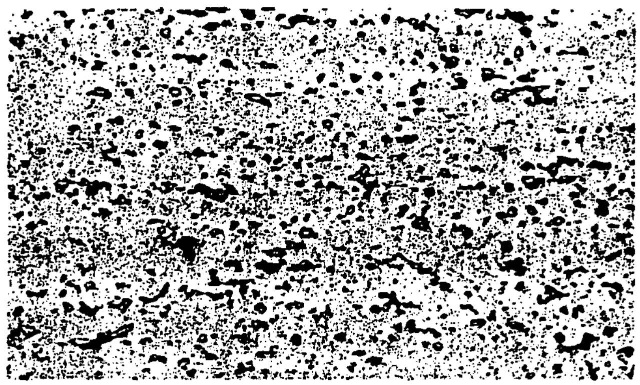
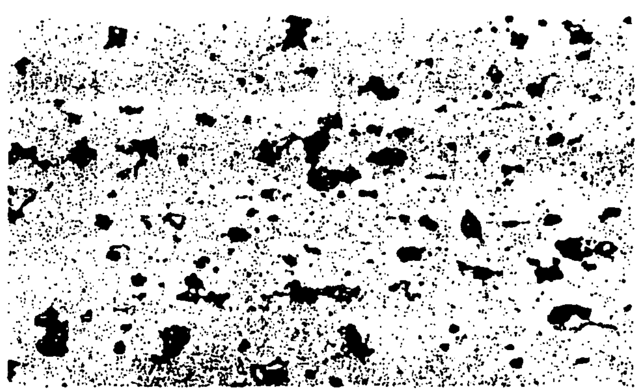

WEAR AMOUNT (mm³)
8
7
6
5
4
3
2
1
COMP-B
B36~ B42
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 14



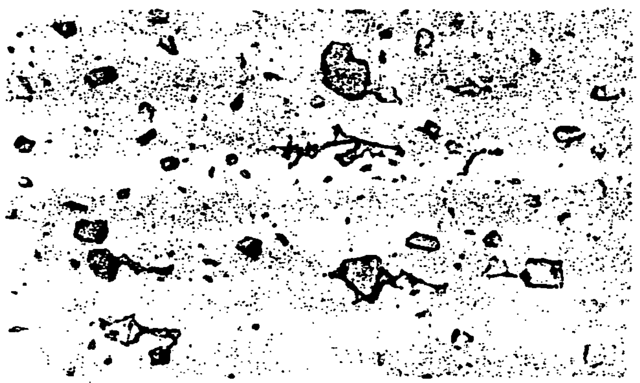
(x400)

Fig. 15



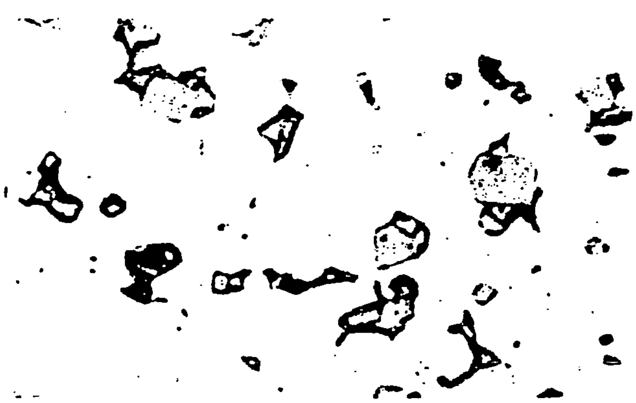
(x400)

Fig. 16



(x400)

Fig. 17



(x400)

Fig. 18

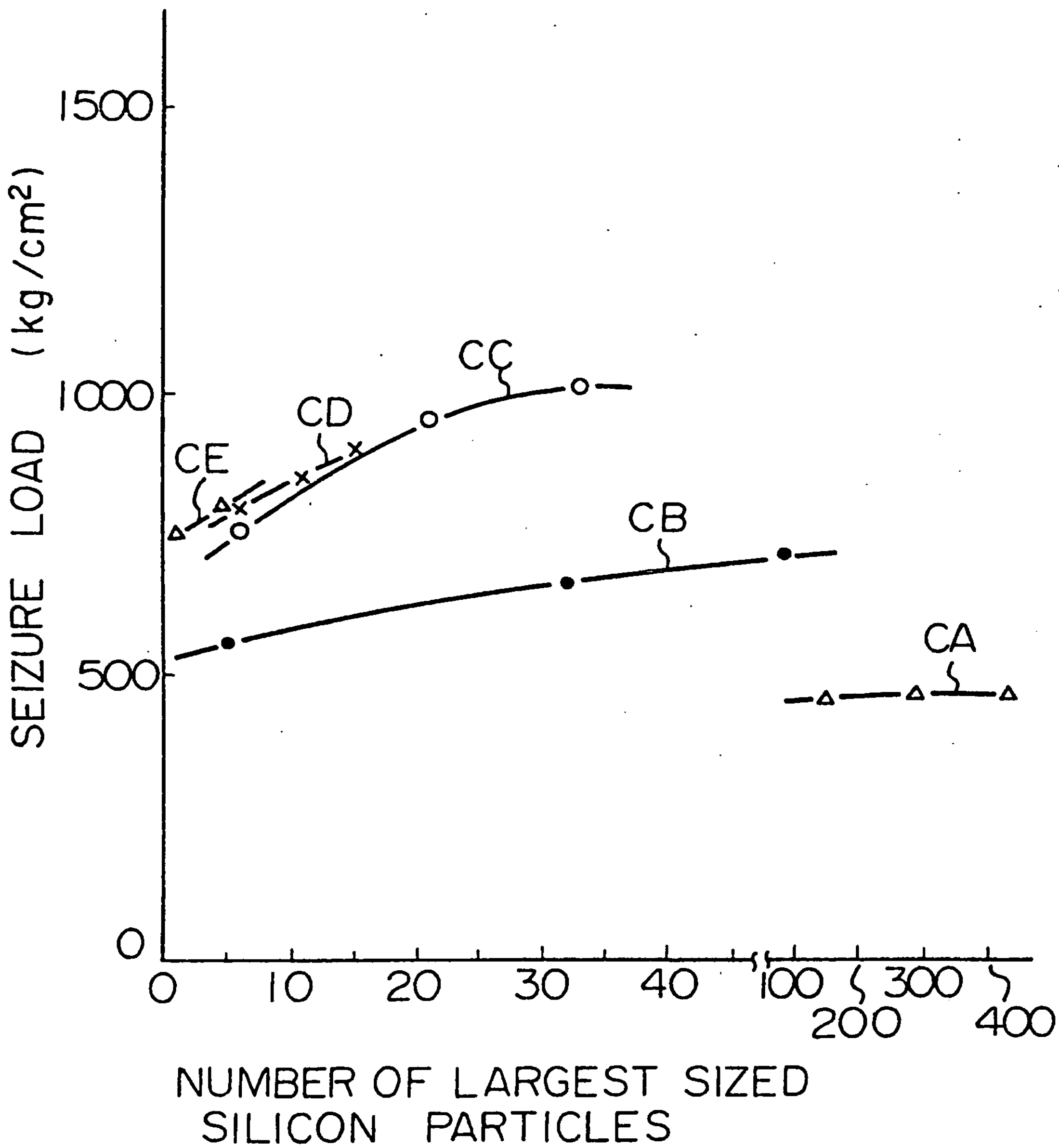

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
CC
CD
CE
CB
CA
0
10
20
30
40
100
200
300
400
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 19

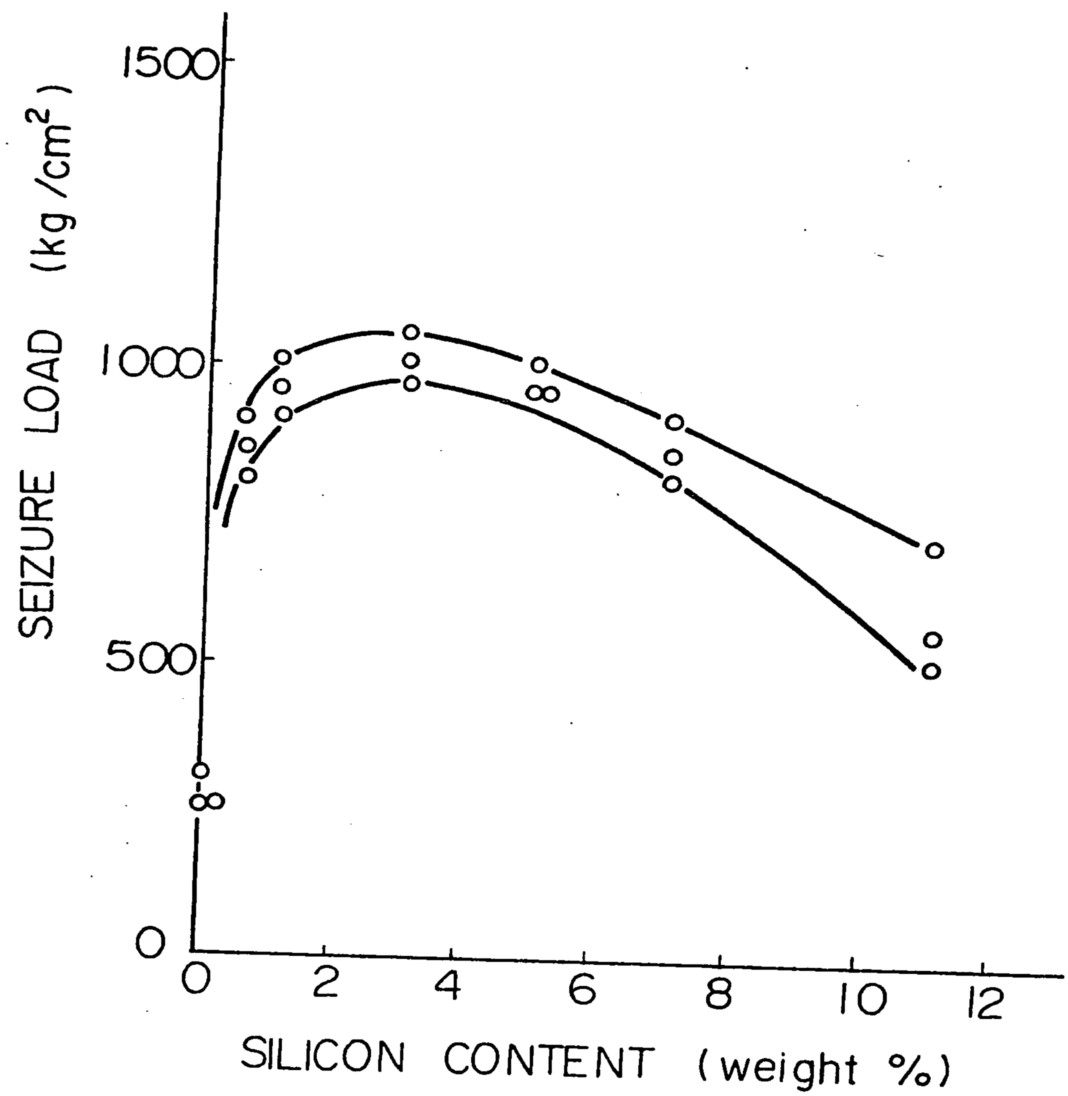
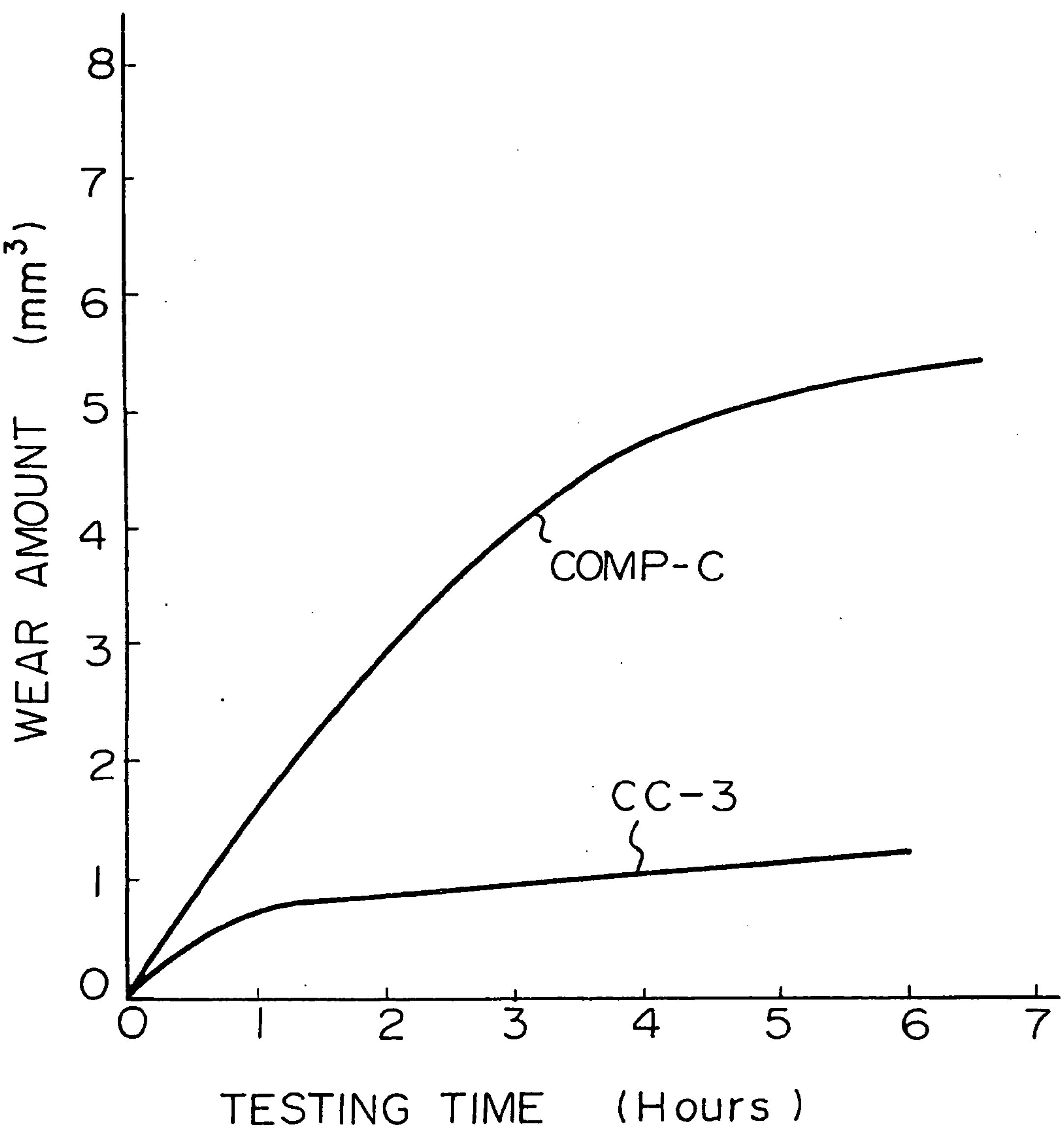

1500
1000
500
0
SEIZURE LOAD (kg/cm²)
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 20



WEAR AMOUNT (mm³)
8
7
6
5
4
3
2
1
0
COMP-C
CC-3
0
1
2
3
4
5
6
7
TESTING TIME (Hours)

Fig. 21

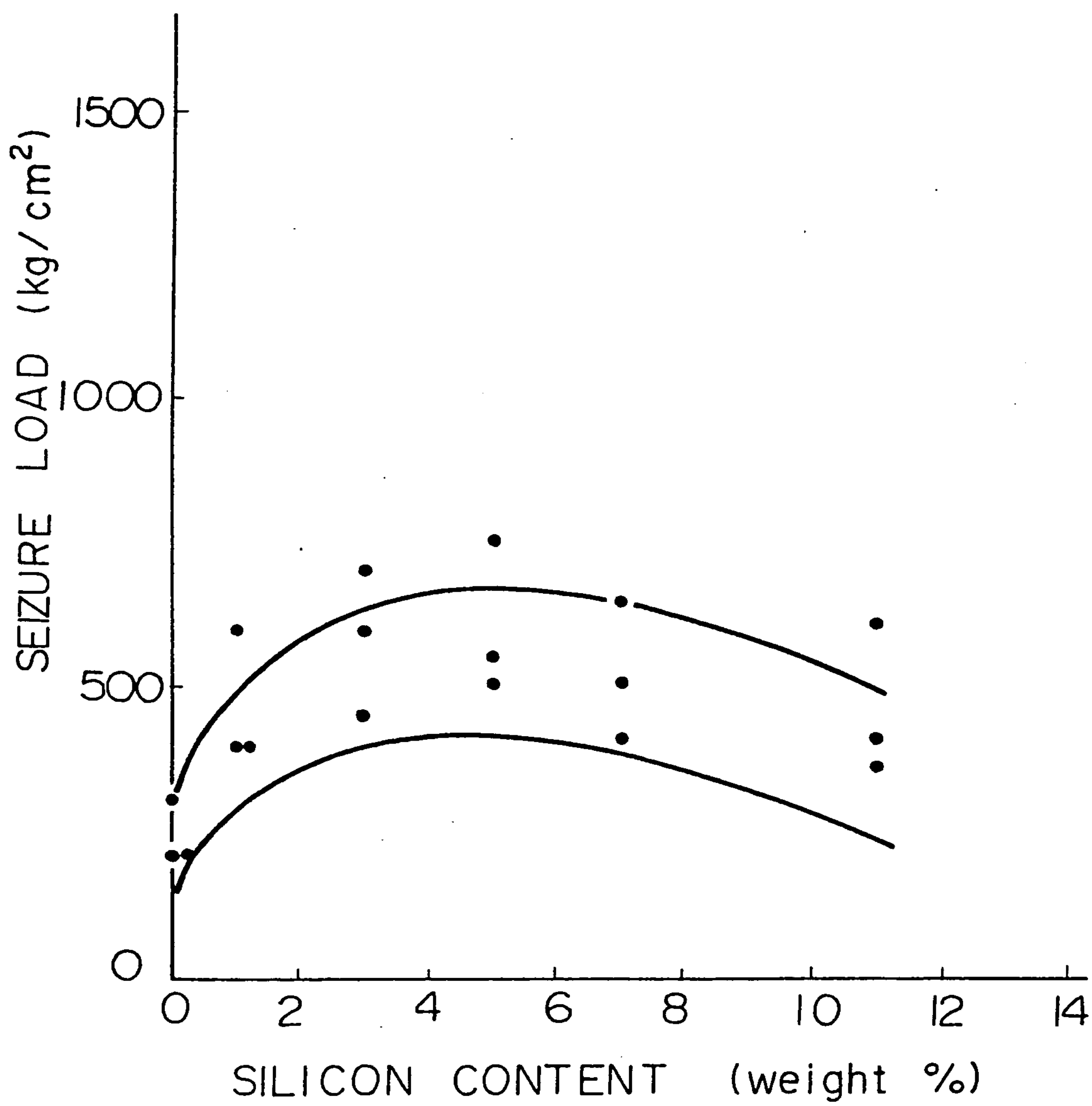

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
0
2
4
6
8
10
12
14
SILICON CONTENT (weight %)

Fig. 22

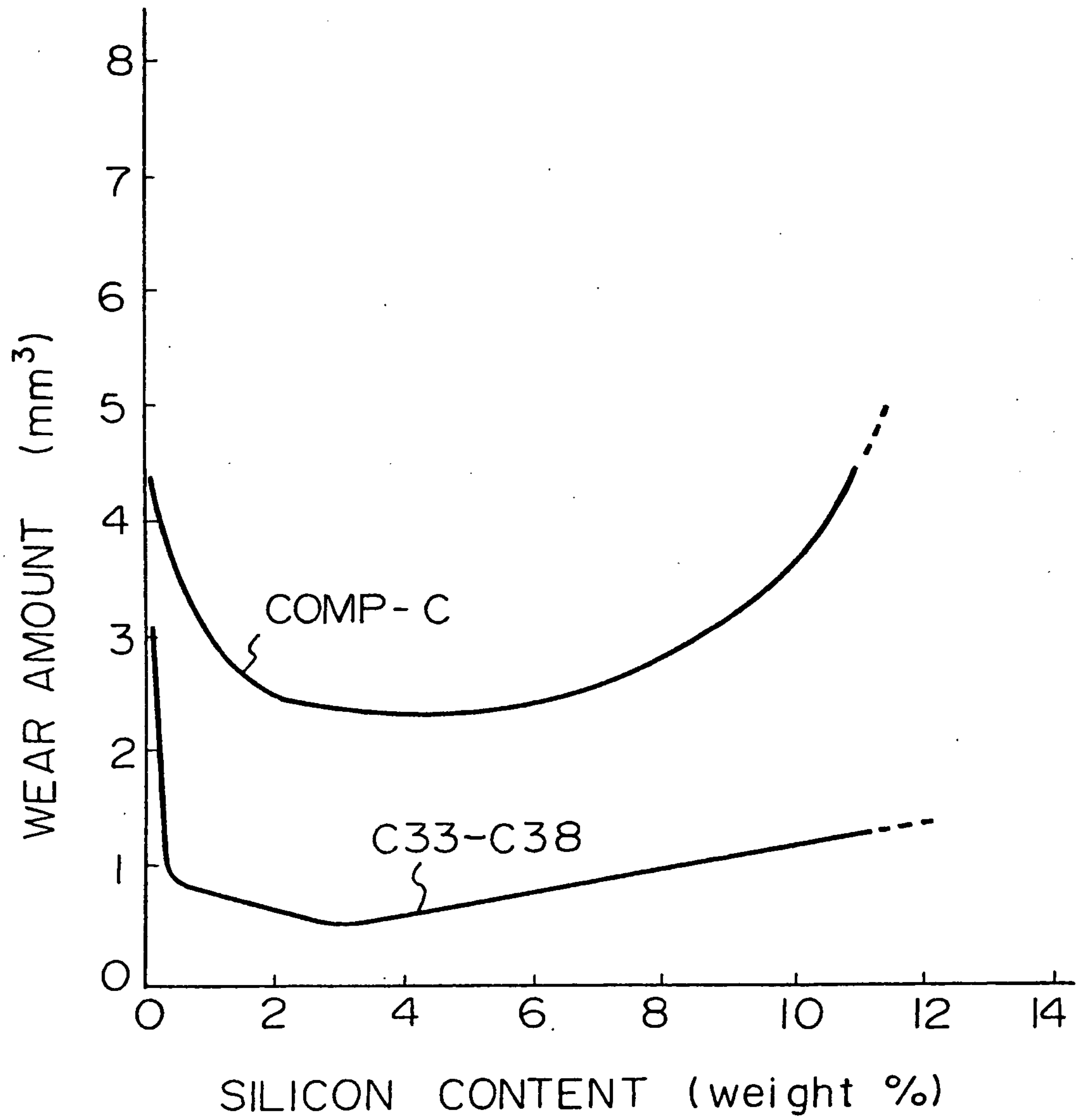

8
7
6
5
4
3
2
1
0
WEAR AMOUNT (mm³)
COMP- C
C33-C38
0
2
4
6
8
10
12
14
SILICON CONTENT (weight %)

Fig. 23

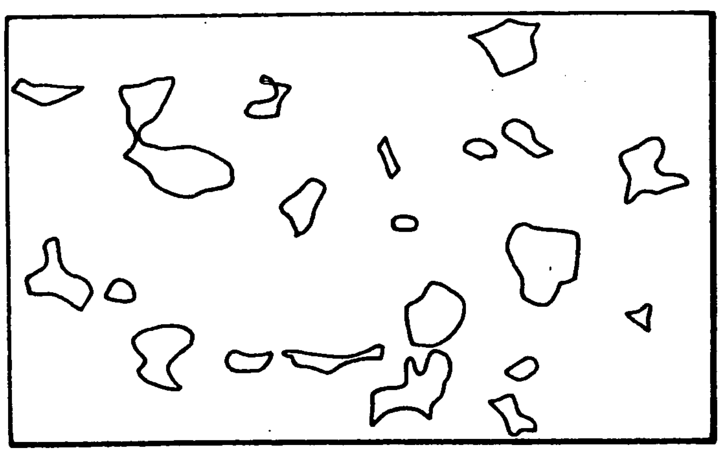


Fig. 24

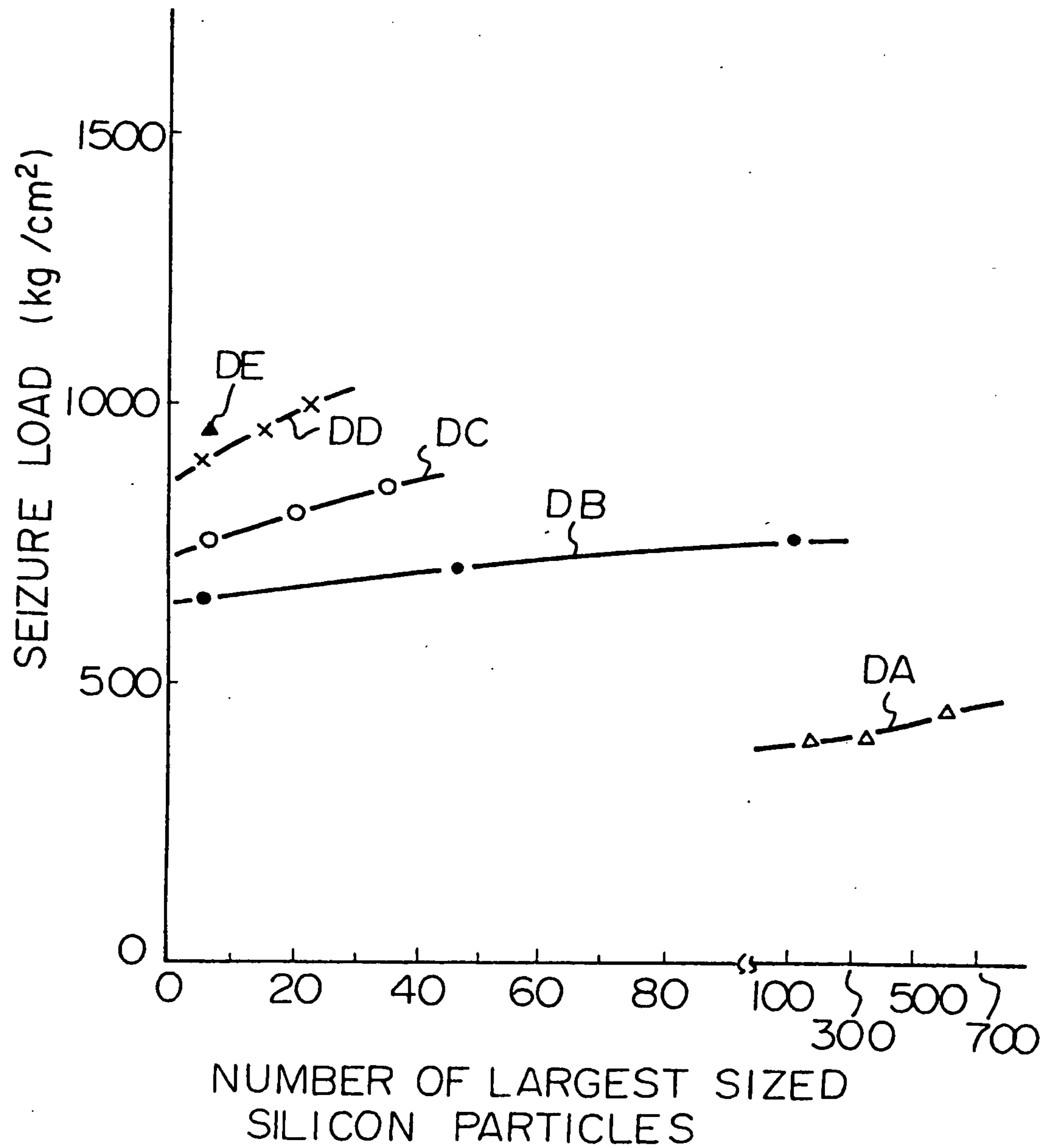
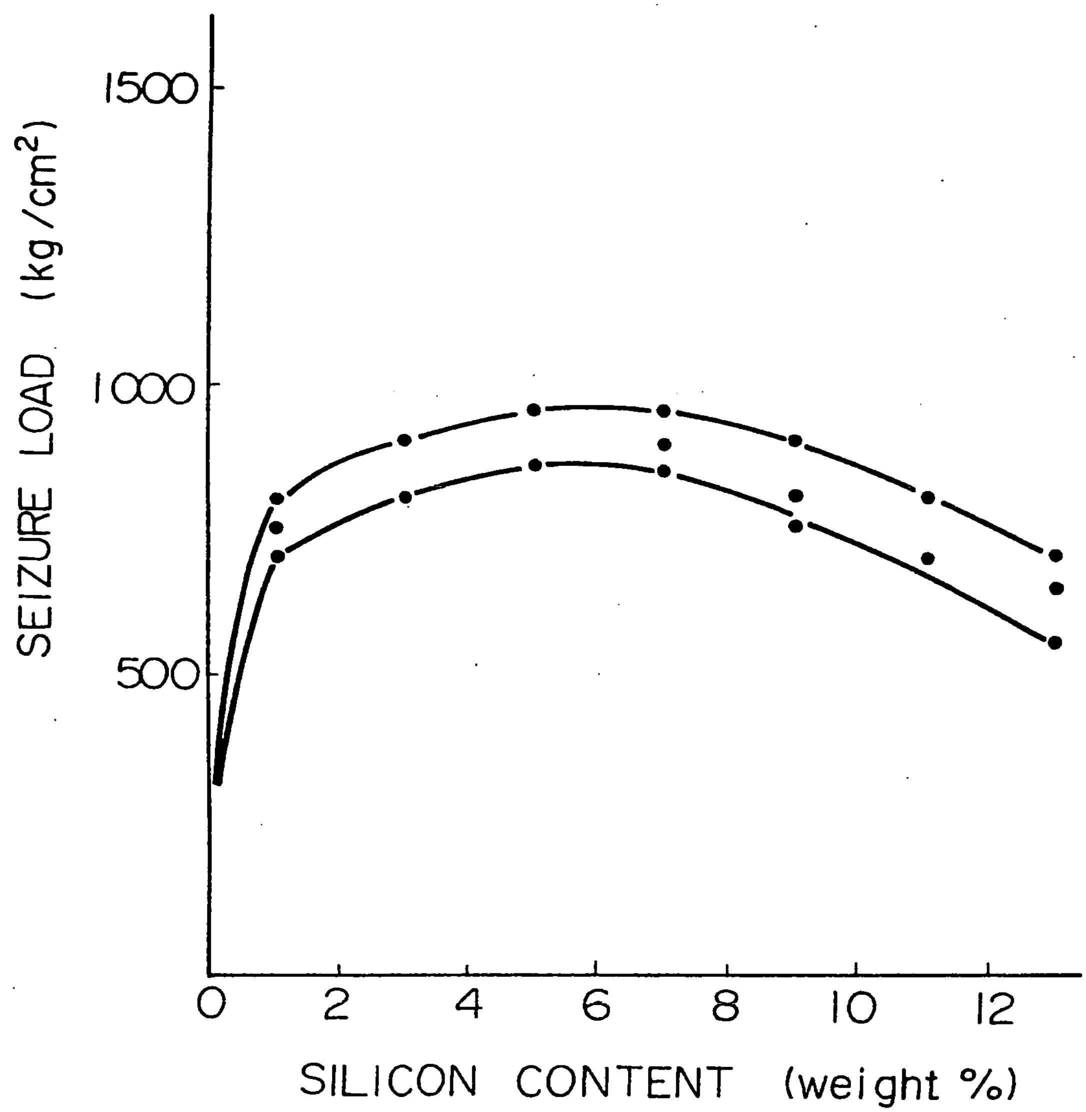
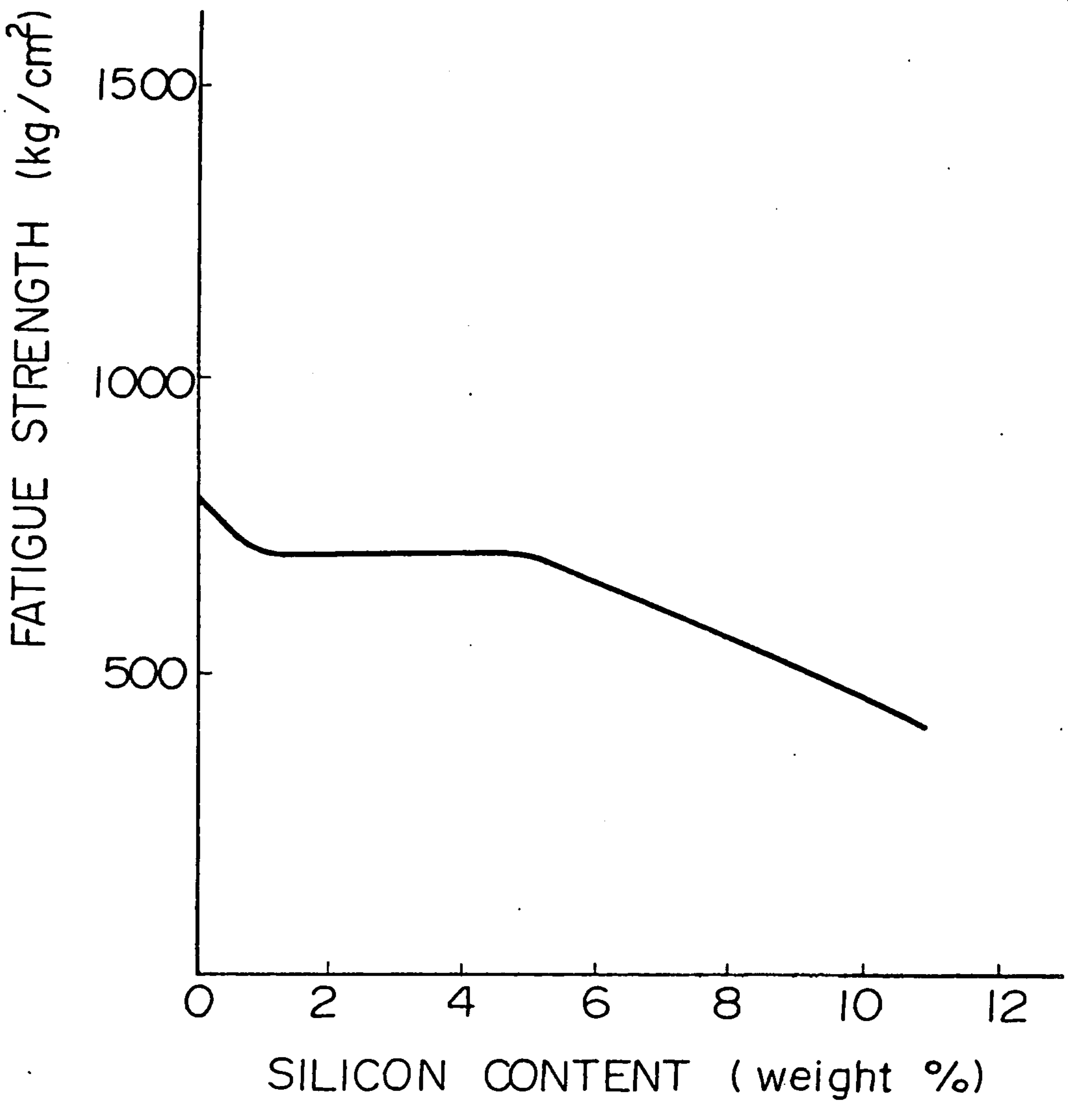

SEIZURE LOAD (kg /cm²)
1500
1000
500
0
DE
DD
DC
DB
DA
0
20
40
60
80
100
300
500
700
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 25



1500
1000
500
SEIZURE LOAD (kg/cm²)
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 26



FATIGUE STRENGTH (kg/cm²)
1500
1000
500
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 27

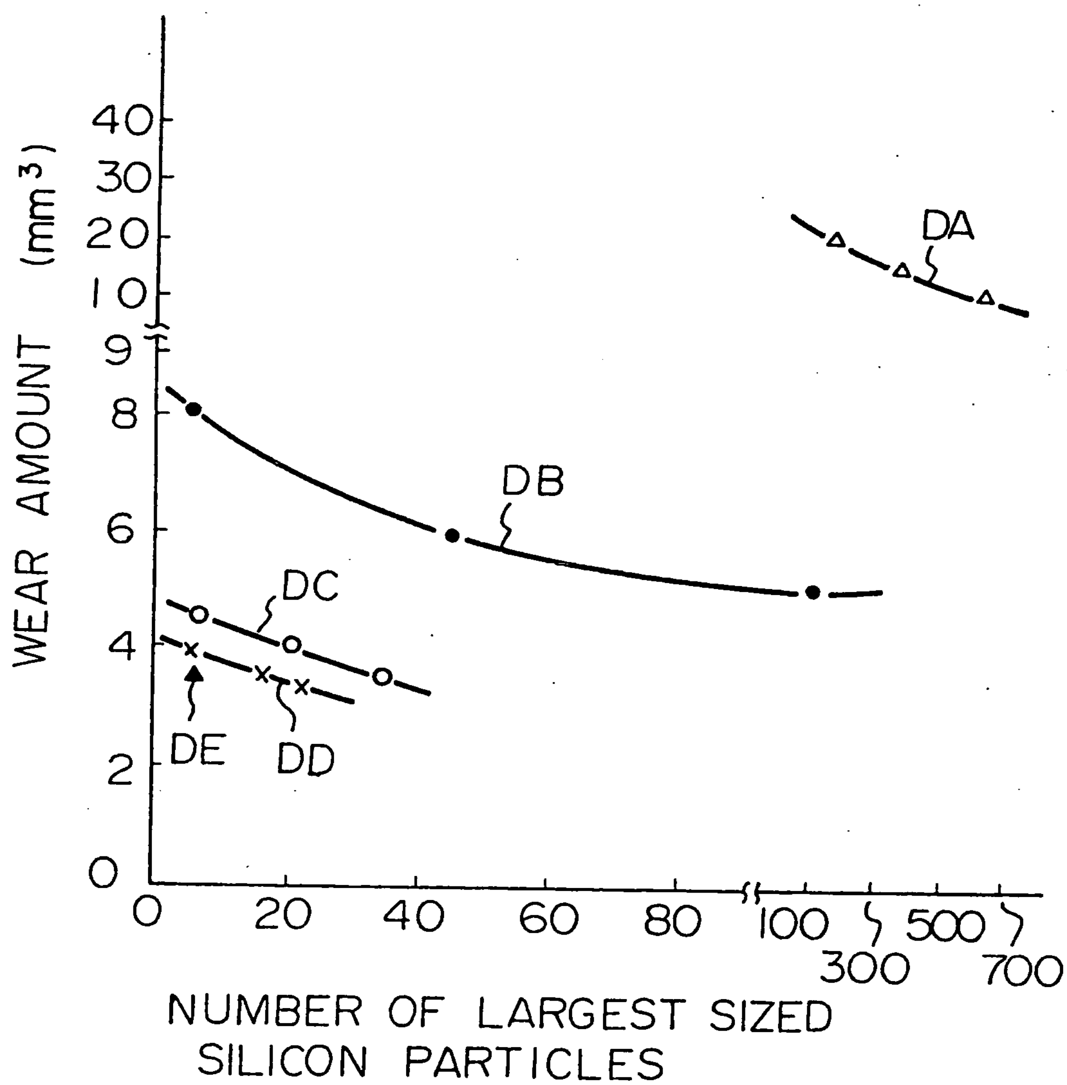

WEAR AMOUNT (mm³)
40
30
20
10
9
8
6
4
2
0
DA
DB
DC
DD
DE
0
20
40
60
80
100
300
500
700
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 28

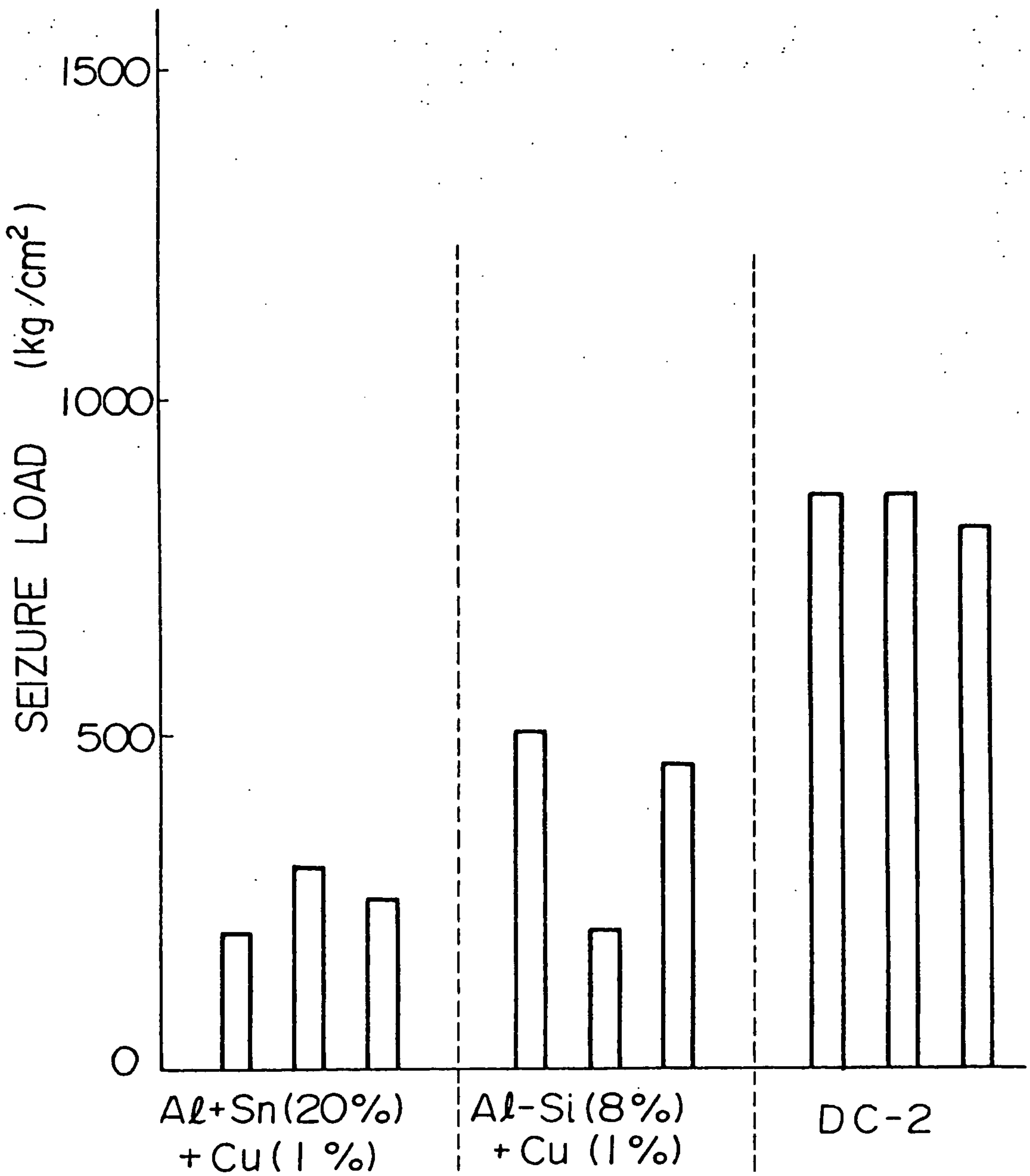


Fig. 29

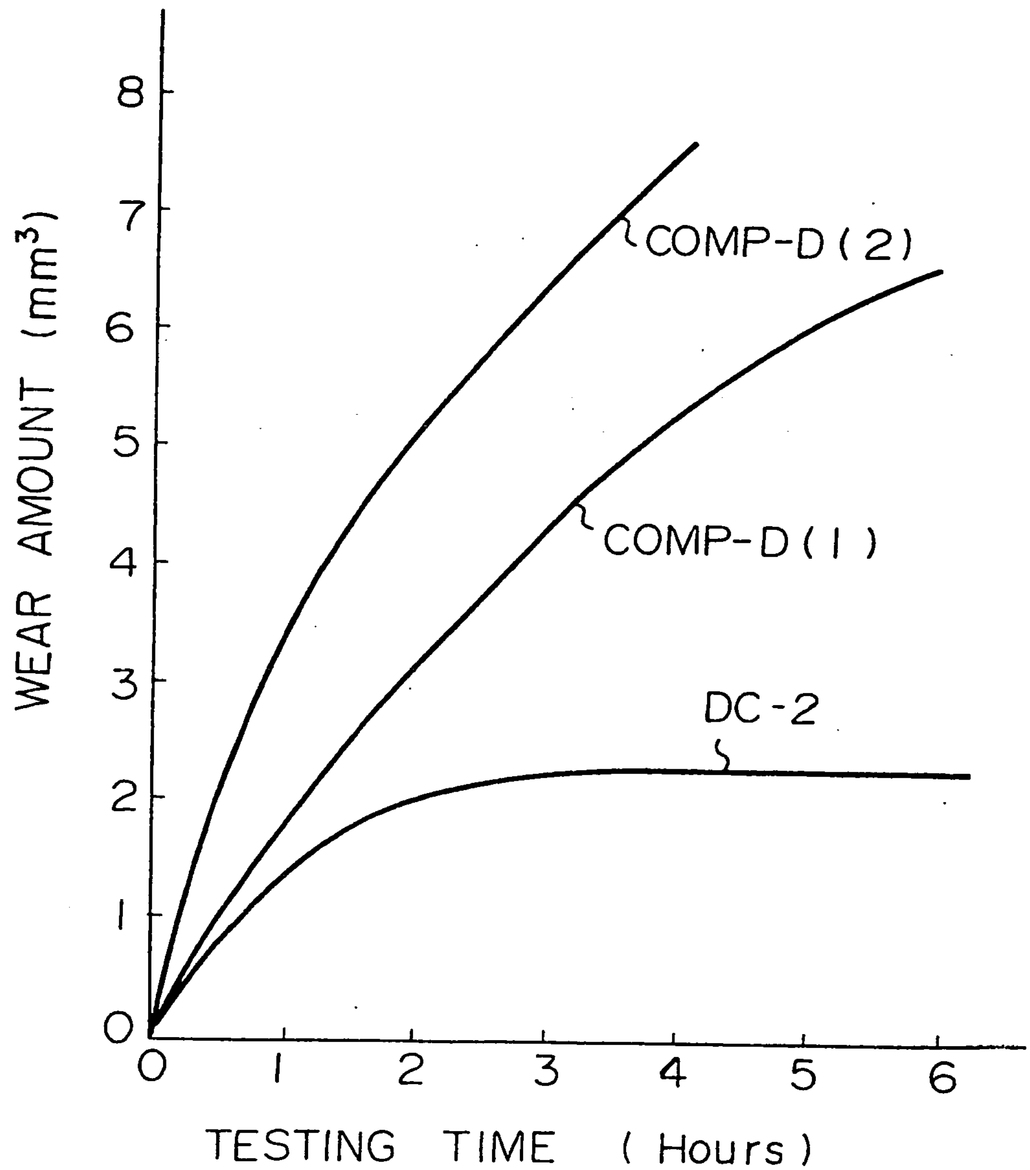

WEAR AMOUNT (mm³)
8
7
6
5
4
3
2
1
0
COMP-D(2)
COMP-D(1)
DC-2
0
1
2
3
4
5
6
TESTING TIME (Hours)

Fig. 30

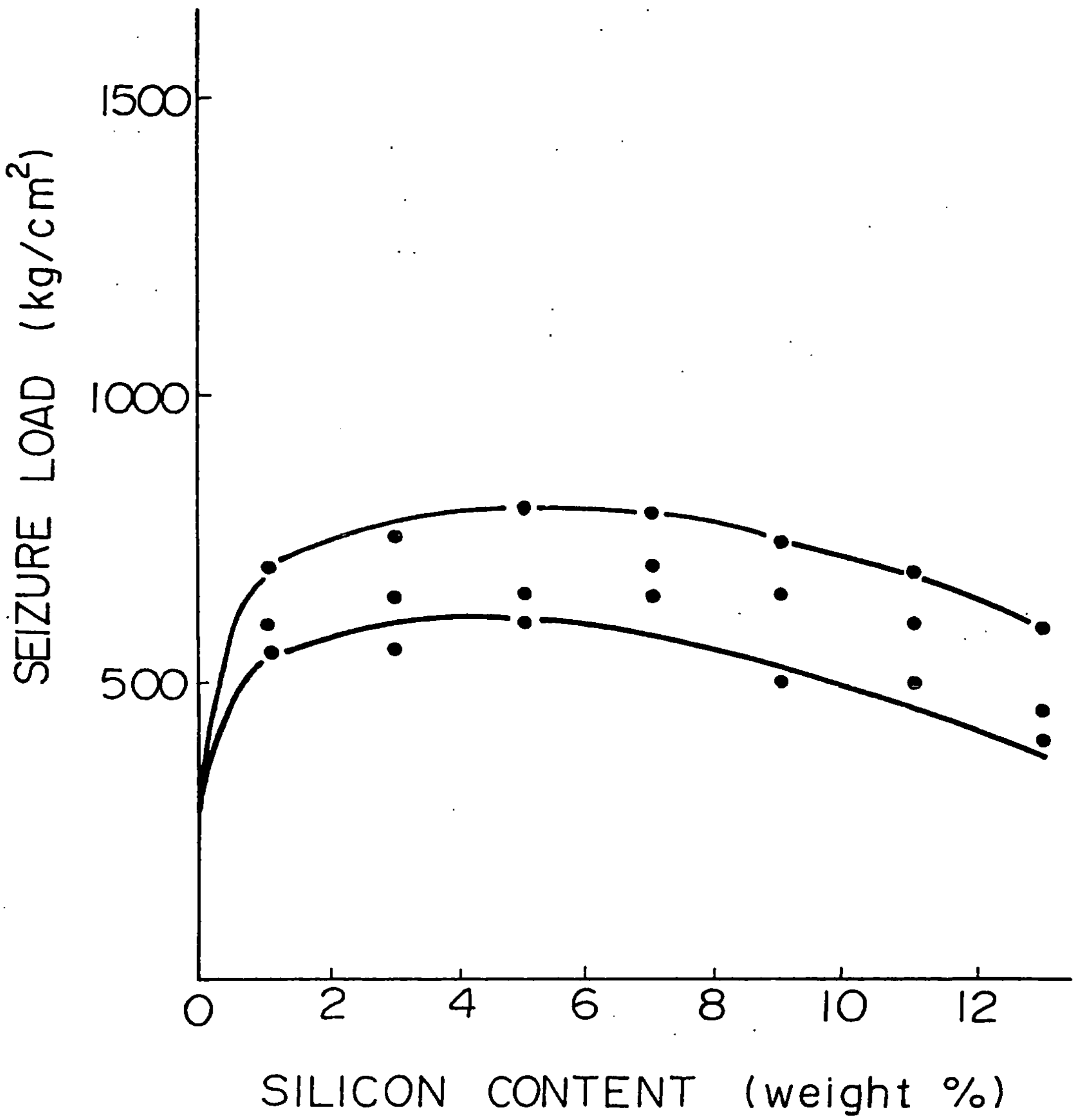

1500
1000
500
SEIZURE LOAD (kg/cm²)
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 31

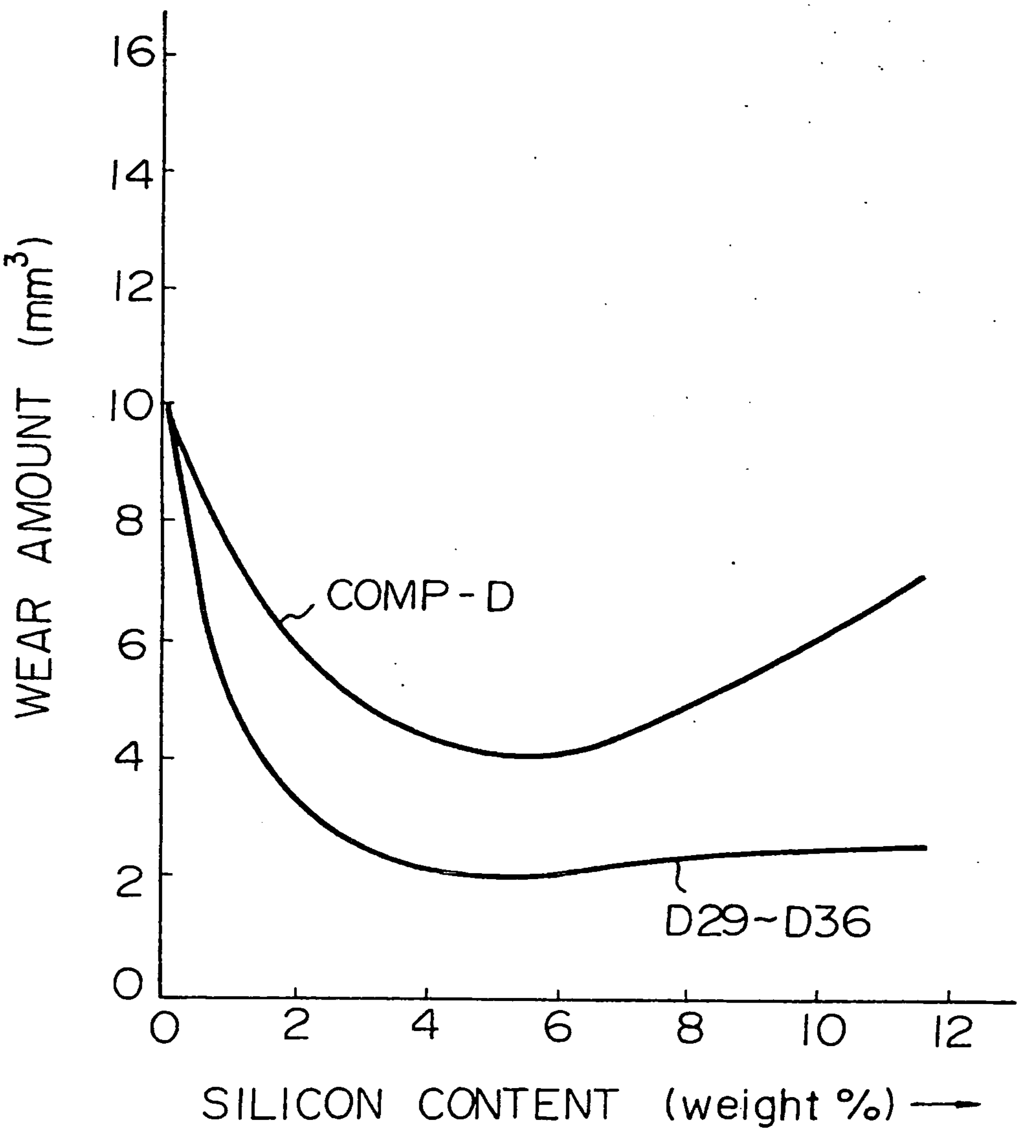
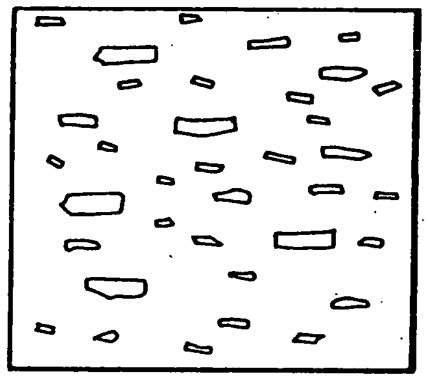
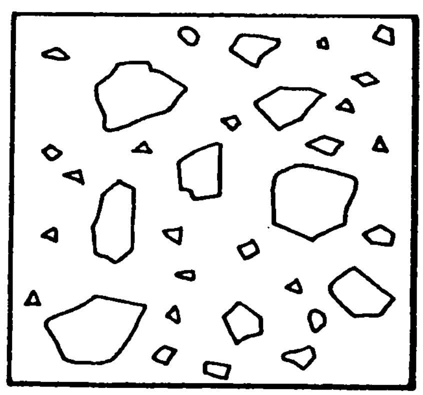

WEAR AMOUNT (mm³)
16
14
12
10
8
6
4
2
0
COMP-D
D29~D36
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 32



(x2000)

Fig. 33



(x400)

Fig. 34

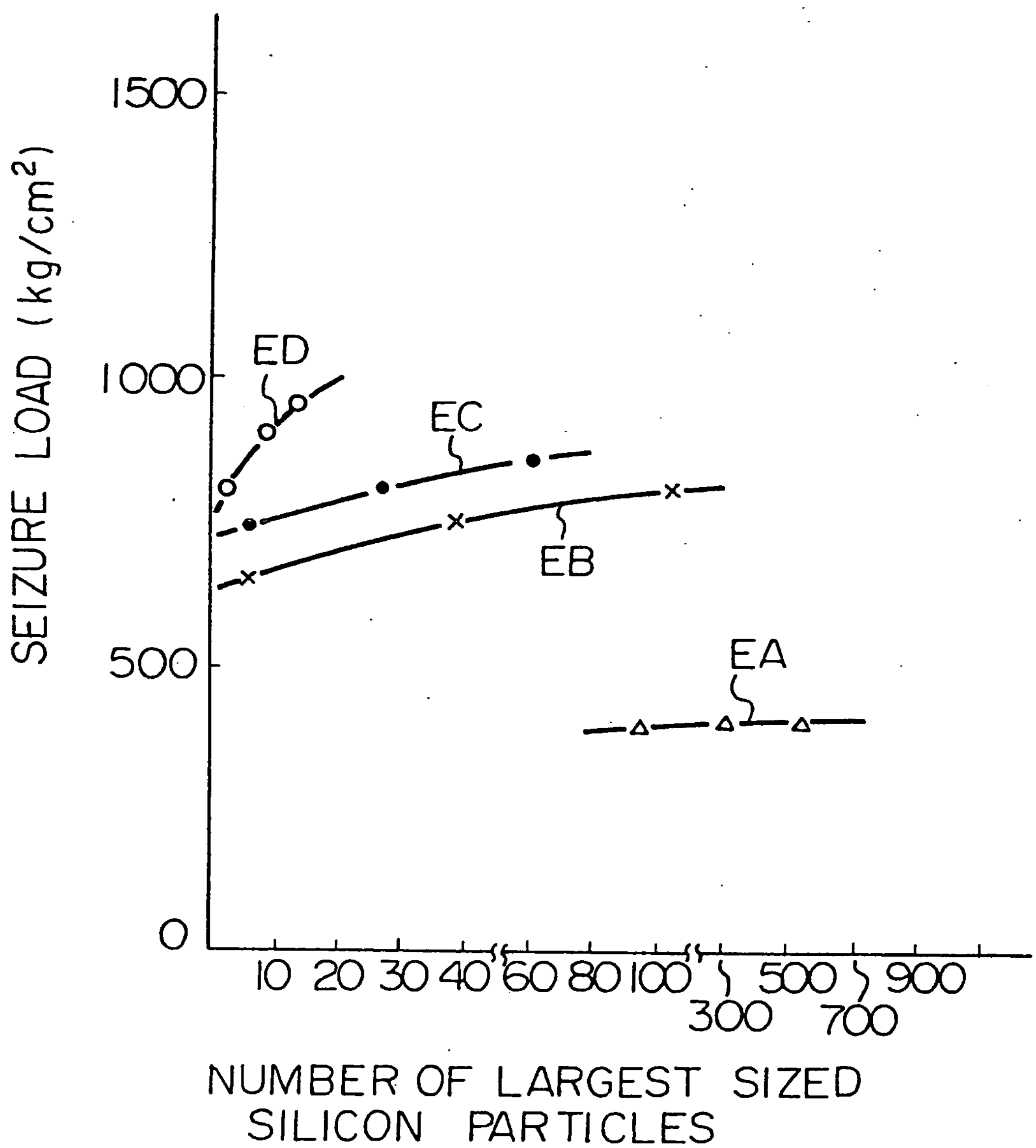

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
ED
EC
EB
EA
10 20 30 40 60 80 100 300 500 700 900
NUMBER OF LARGEST SIZED SILICON PARTICLES

Fig. 35

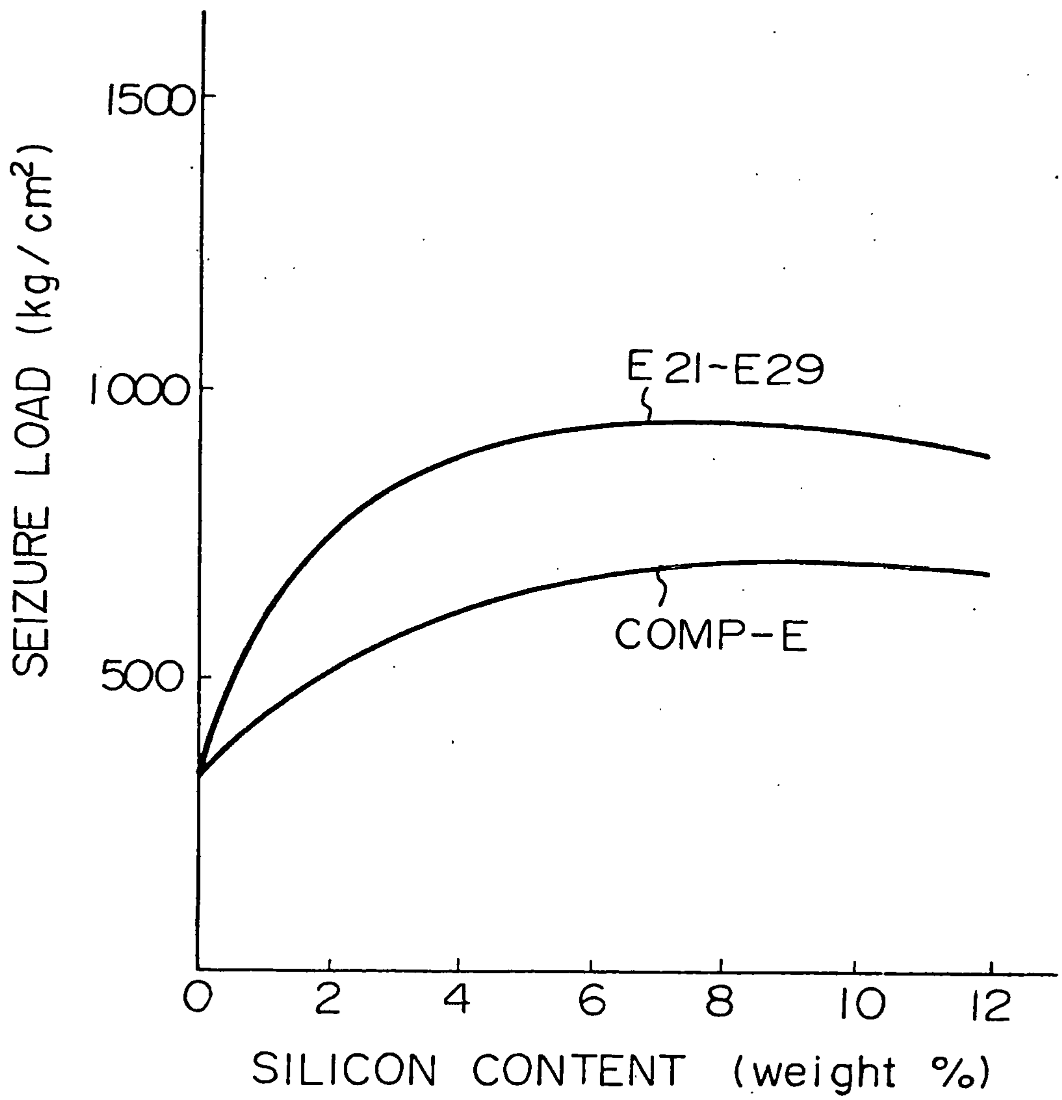

1500
1000
500
SEIZURE LOAD (kg/cm²)
E21~E29
COMP-E
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 36

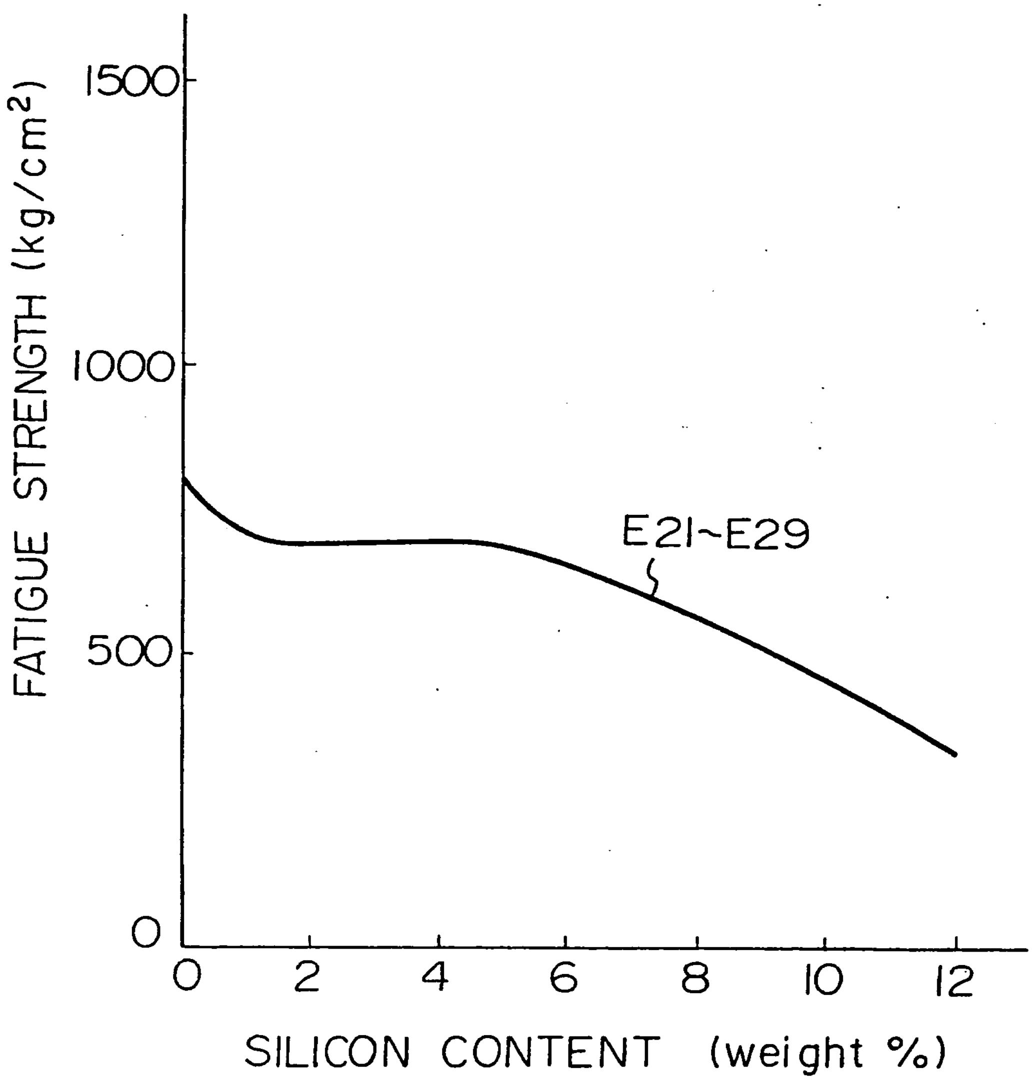

FATIGUE STRENGTH (kg/cm2)
1500
1000
500
0
0
2
4
6
8
10
12
SILICON CONTENT (weight %)
E21~E29

Fig. 37

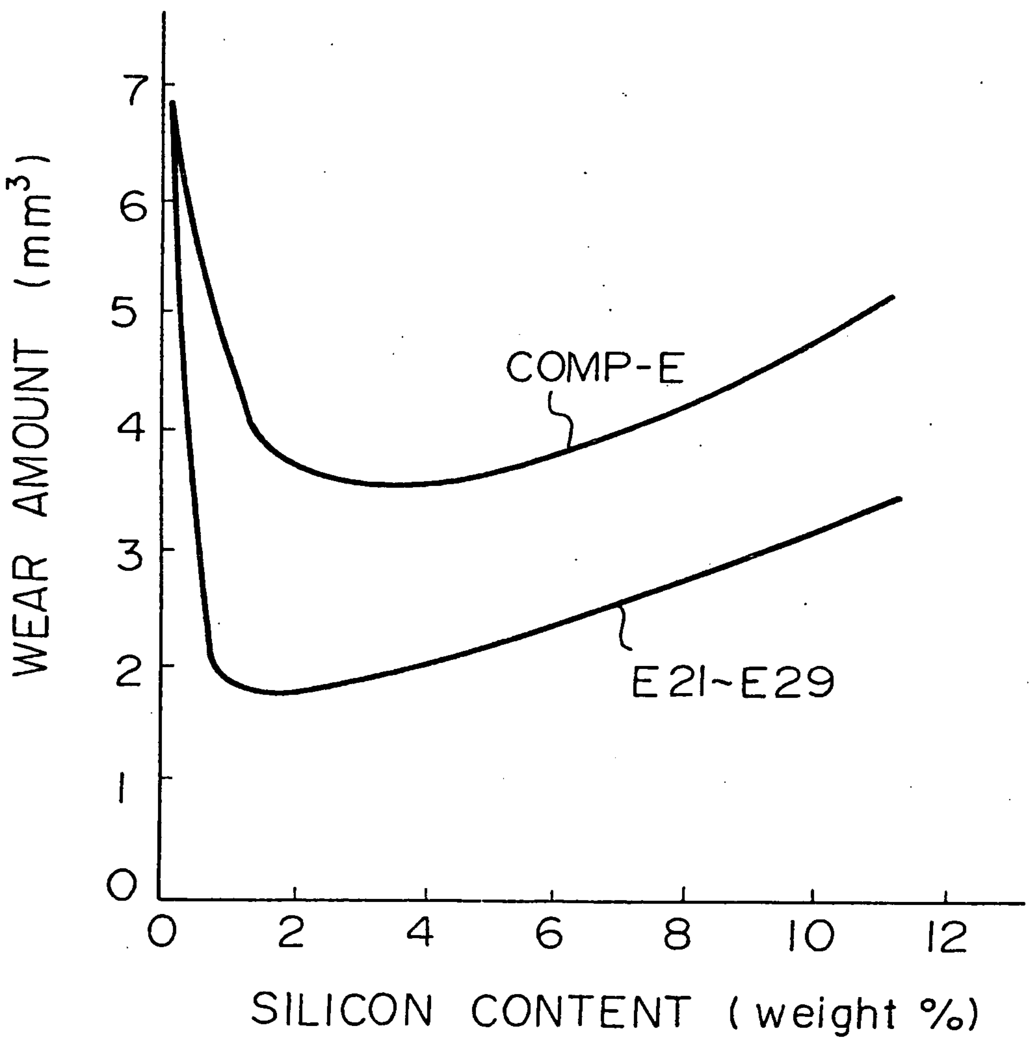

WEAR AMOUNT (mm3)
7
6
5
4
3
2
1
0
COMP-E
E21~E29
0
2
4
6
8
10
12
SILICON CONTENT (weight %)

Fig. 38

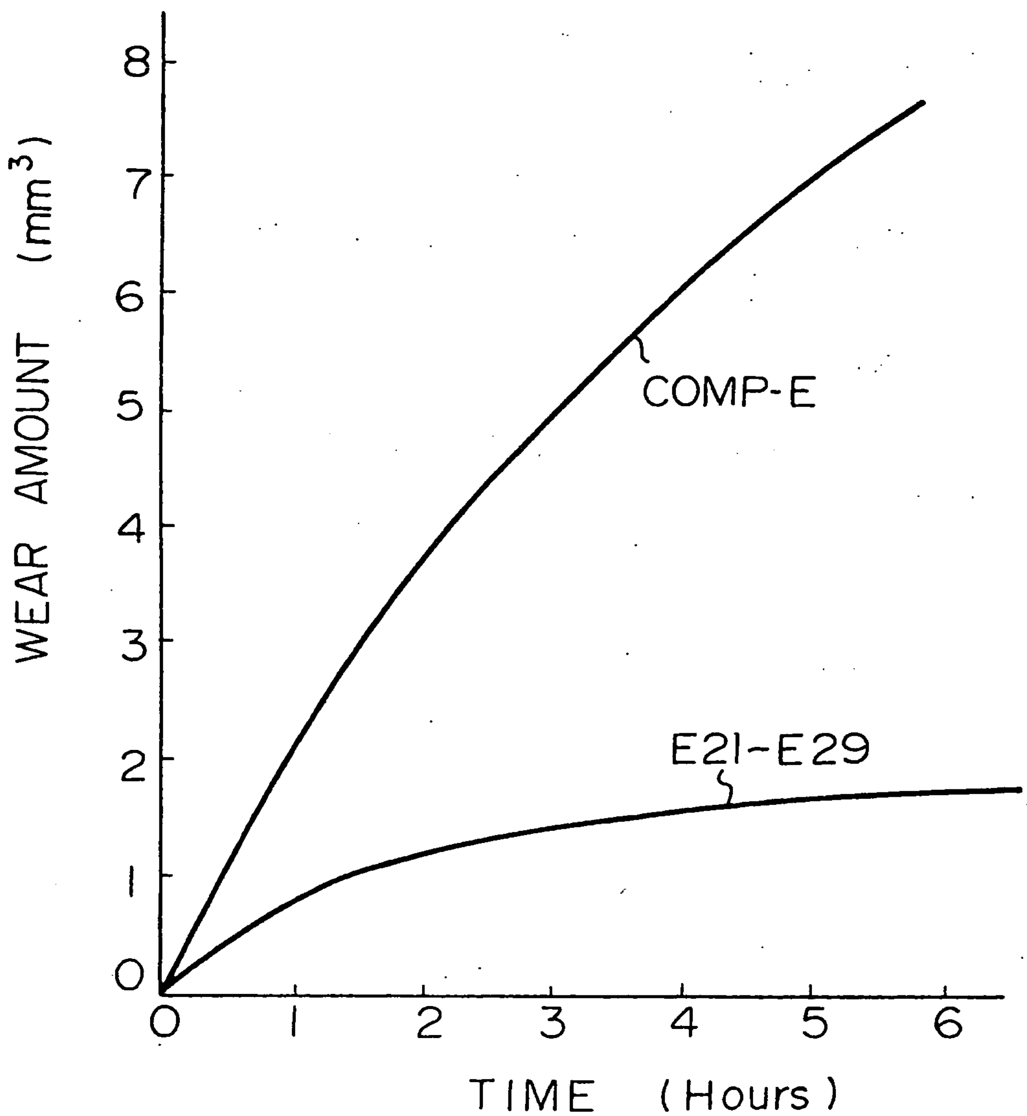


Fig. 39

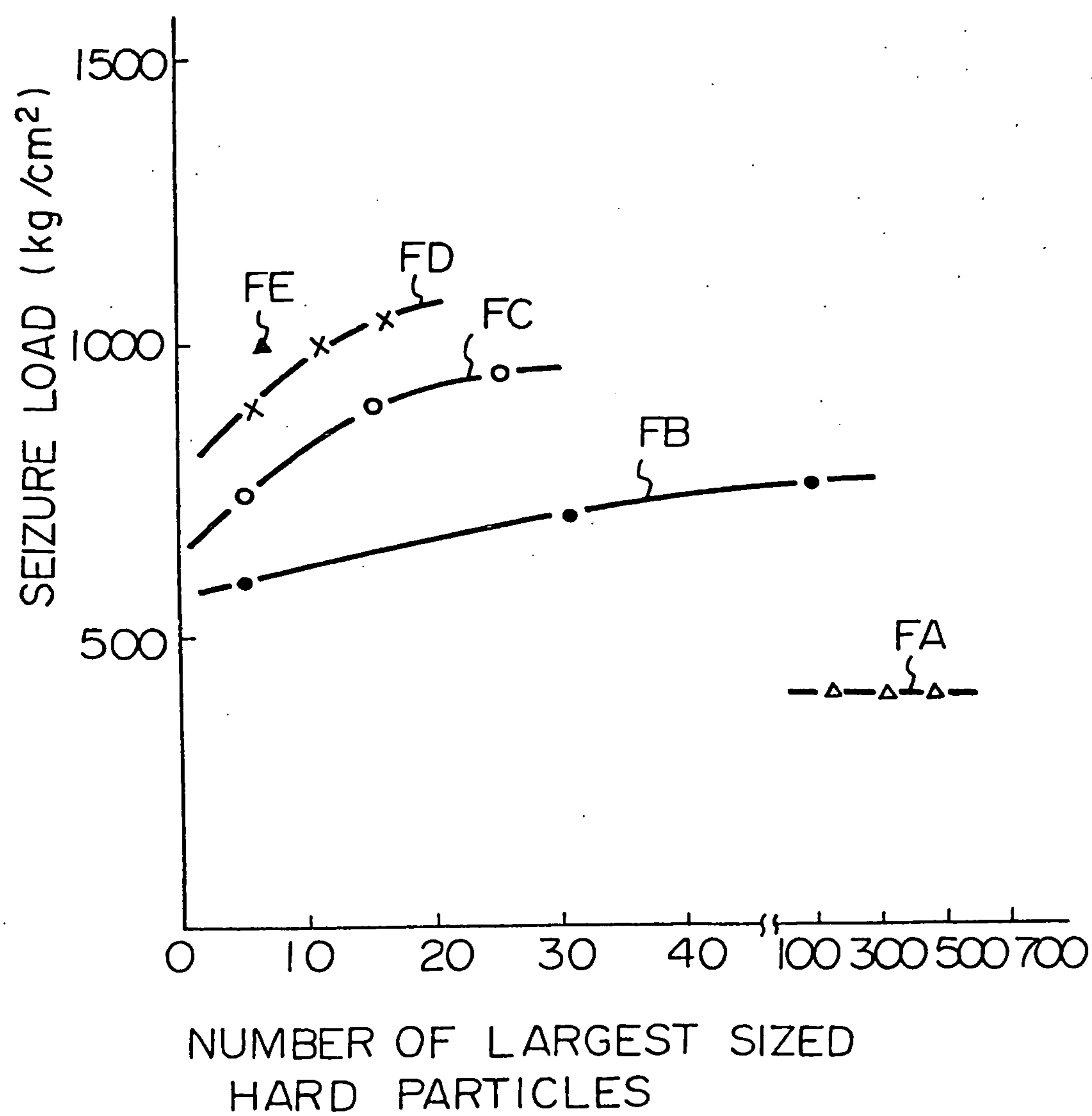

SEIZURE LOAD (kg/cm²)
1500
1000
500
FE
FD
FC
FB
FA
0
10
20
30
40
100
300
500
700
NUMBER OF LARGEST SIZED HARD PARTICLES

Fig. 40

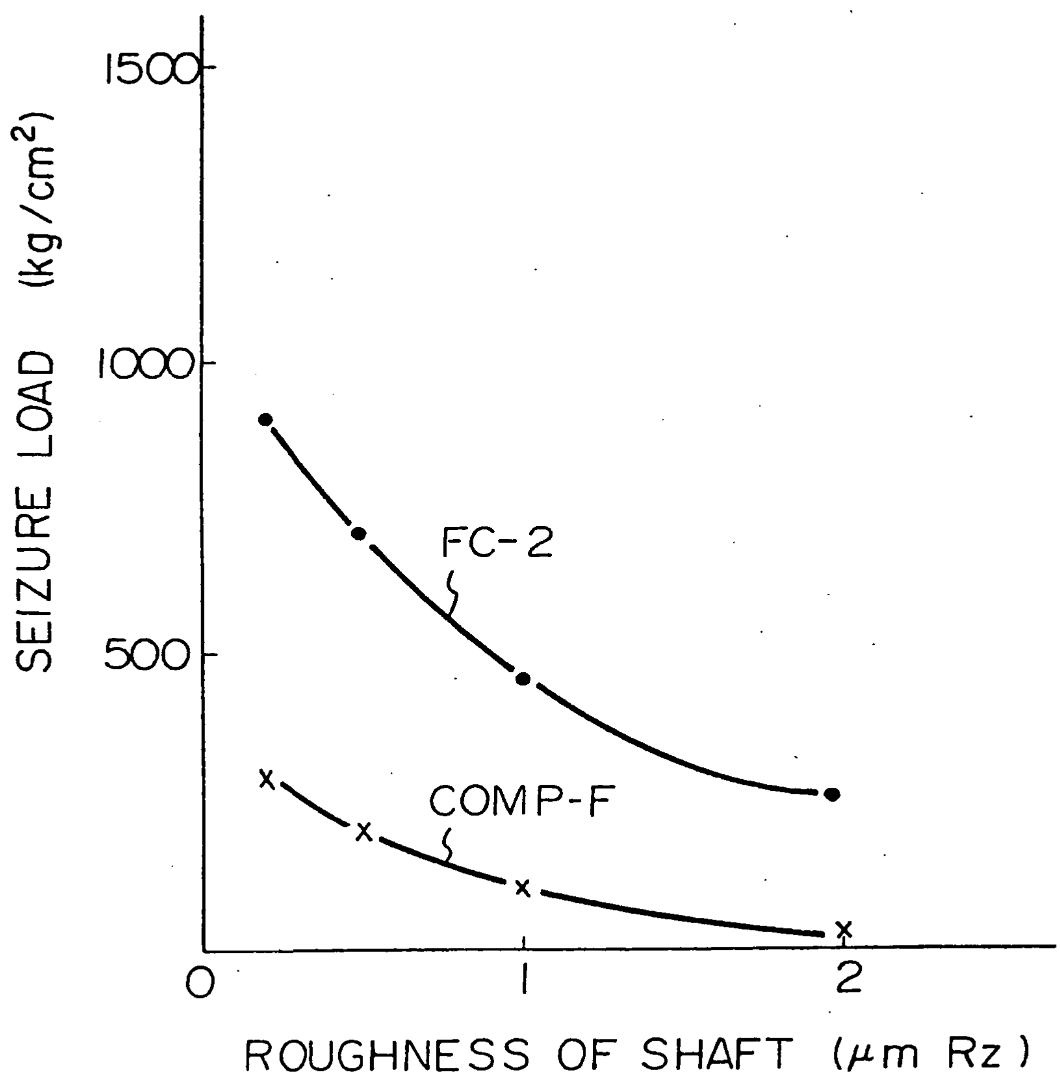
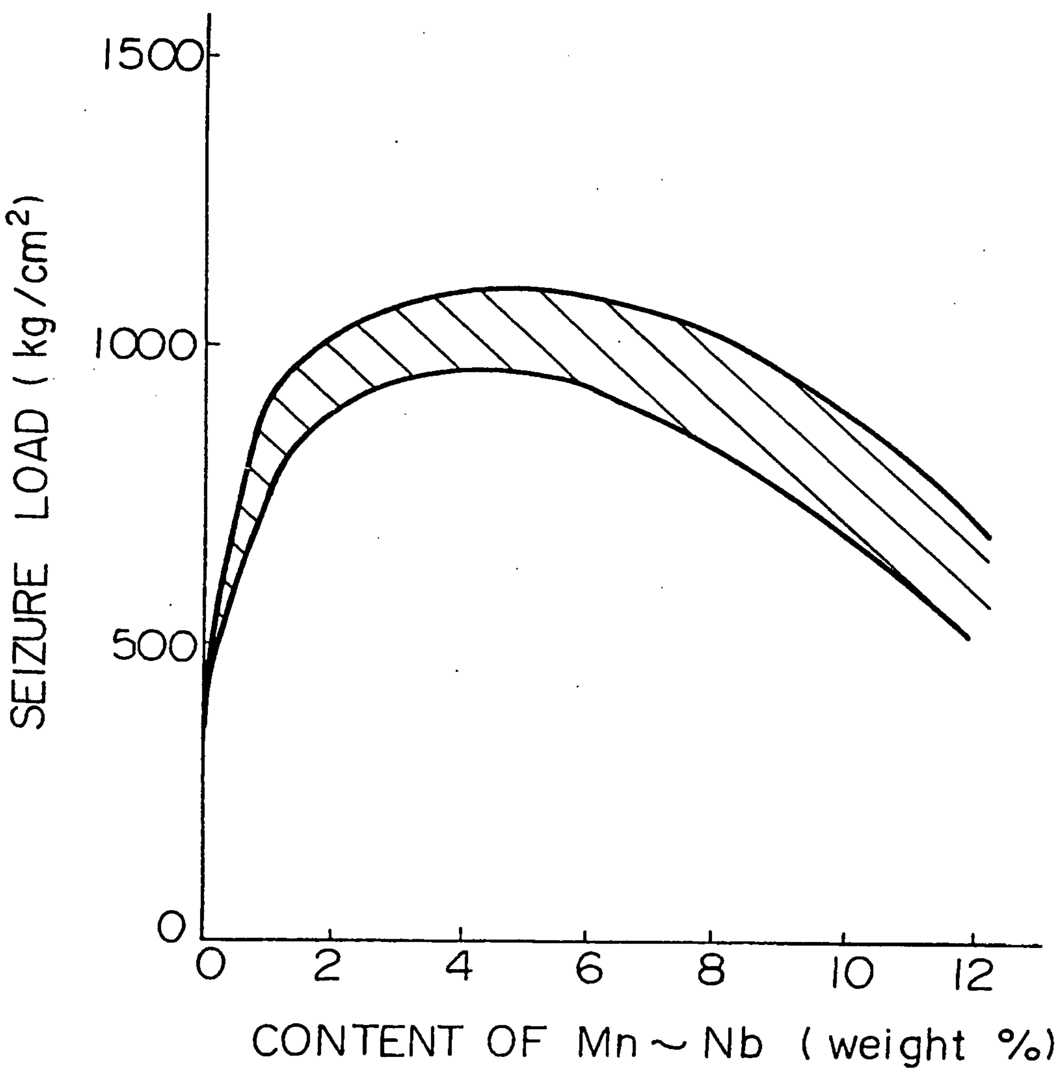

1500
1000
500
SEIZURE LOAD (kg/cm²)
FC-2
COMP-F
0
1
2
ROUGHNESS OF SHAFT (μm Rz)

Fig. 41



SEIZURE LOAD (kg/cm²)
1500
1000
500
0
0
2
4
6
8
10
12
CONTENT OF Mn ~ Nb (weight %)

Fig. 42

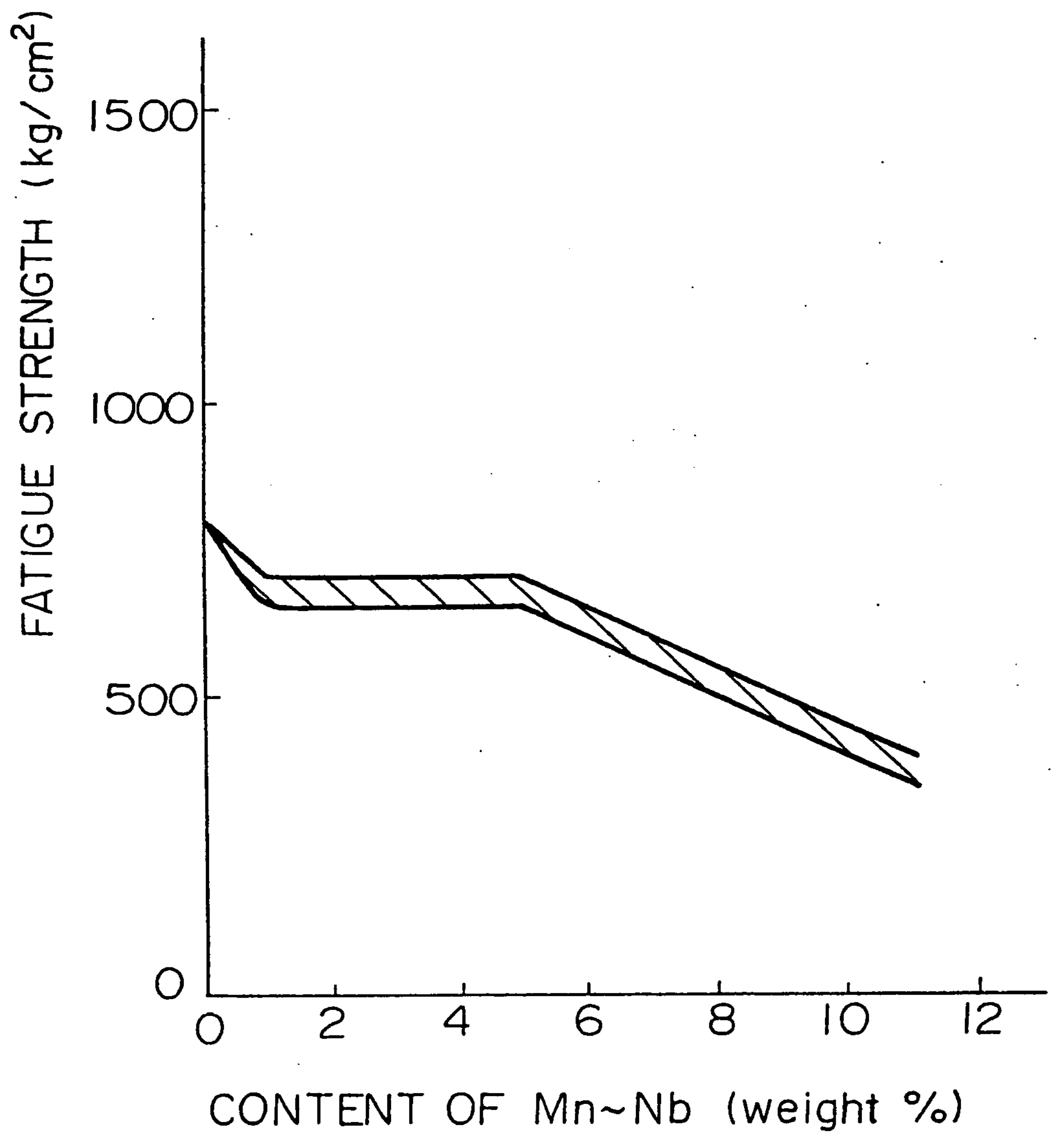

FATIGUE STRENGTH (kg/cm²)
1500
1000
500
0
0
2
4
6
8
10
12
CONTENT OF Mn~Nb (weight %)

Fig. 43

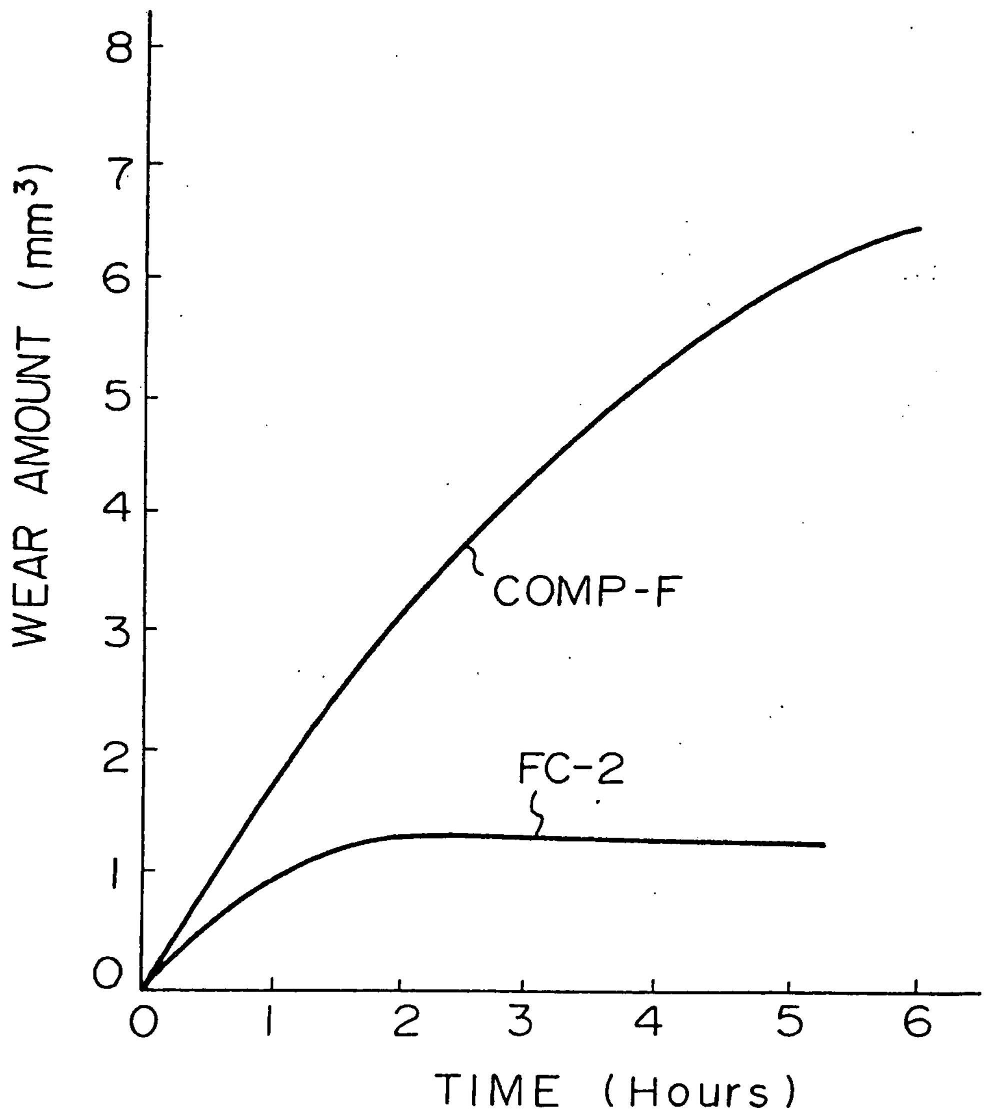


Fig. 44

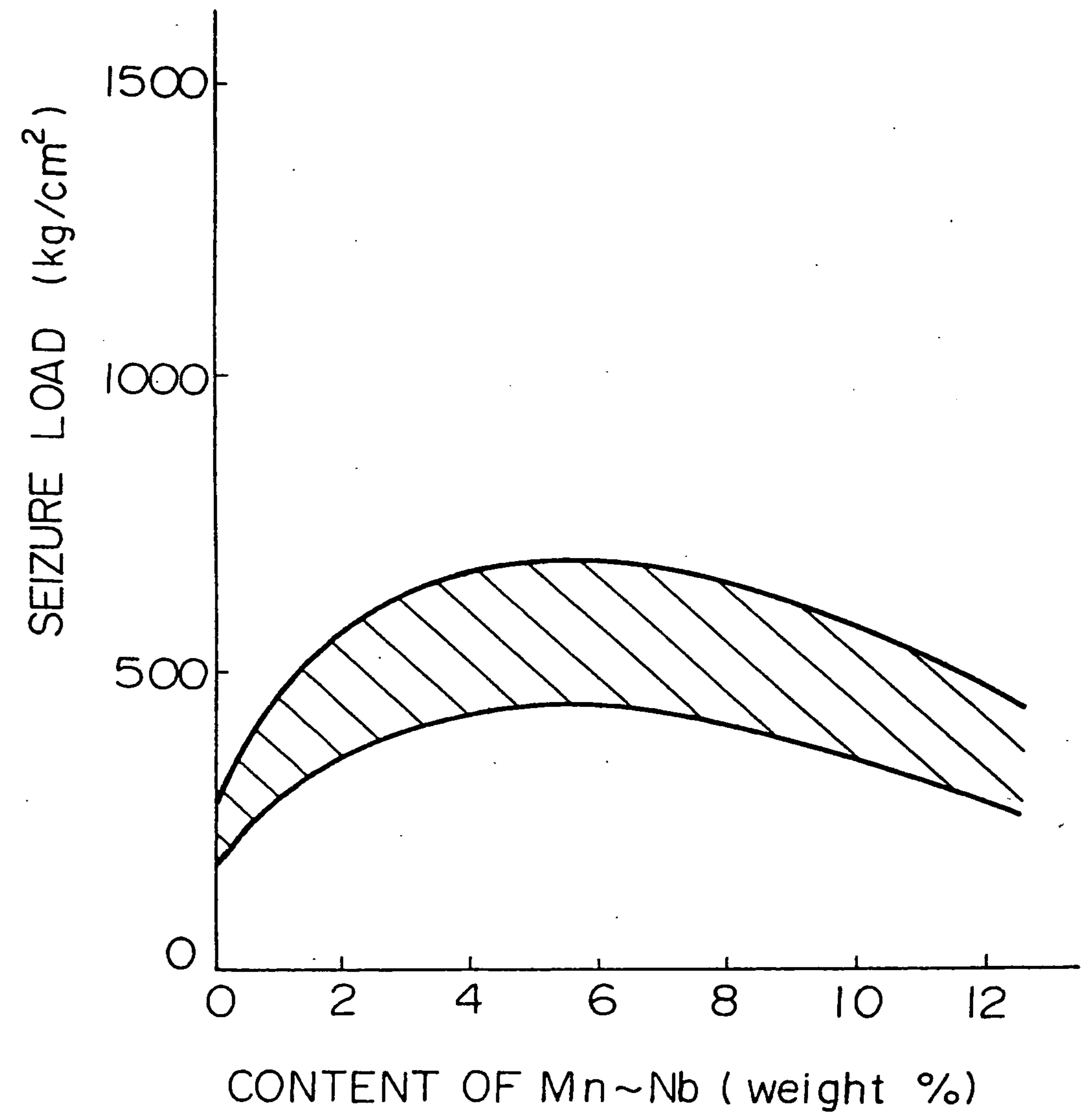
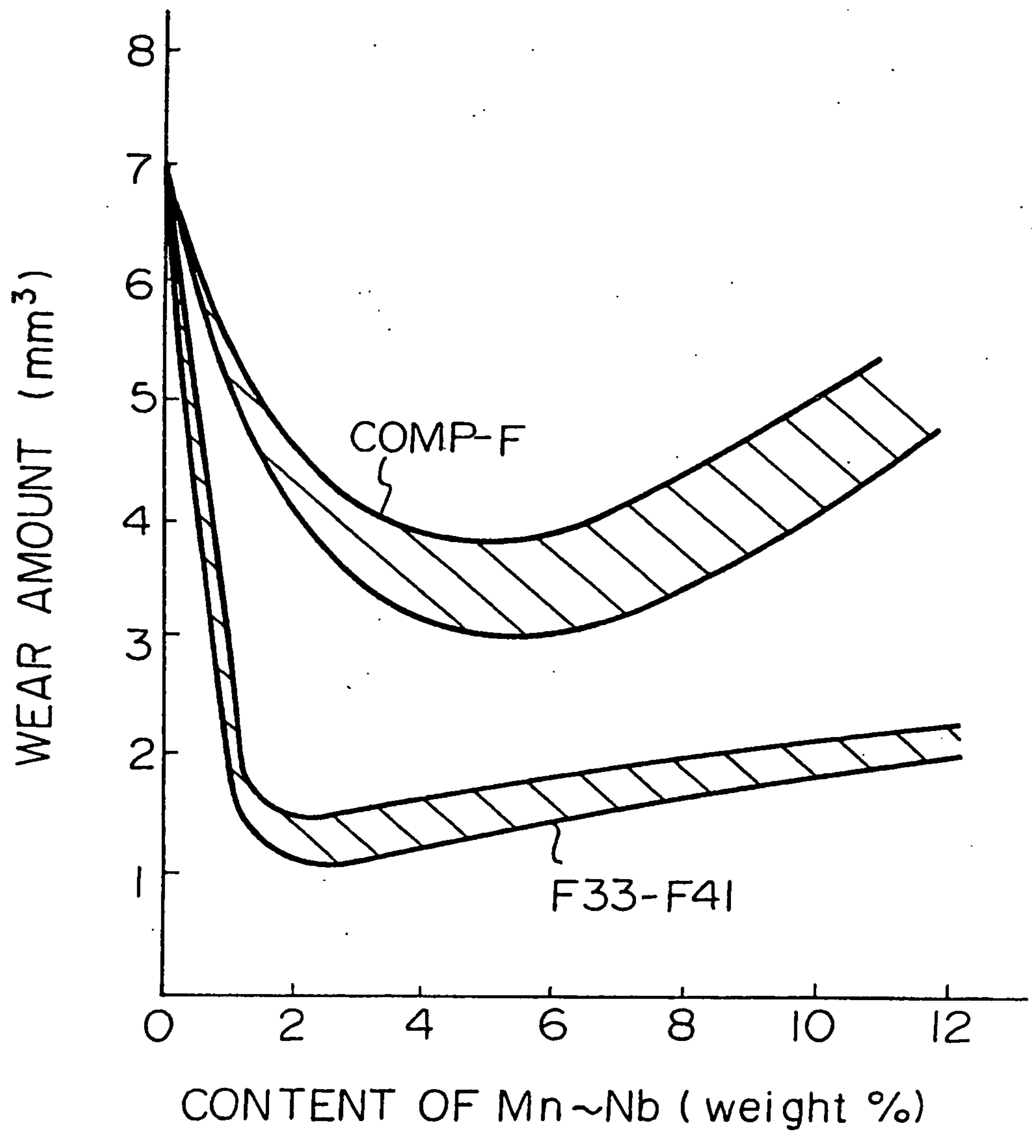
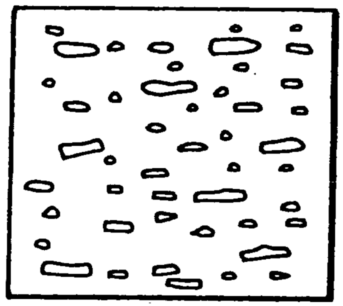

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
0
2
4
6
8
10
12
CONTENT OF Mn~Nb (weight %)

Fig. 45



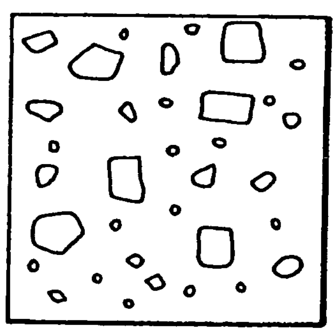
WEAR AMOUNT (mm³)
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
COMP-F
F33-F41
CONTENT OF Mn~Nb (weight %)

Fig. 46



(×2000)

Fig. 47



(×400)

Fig. 48

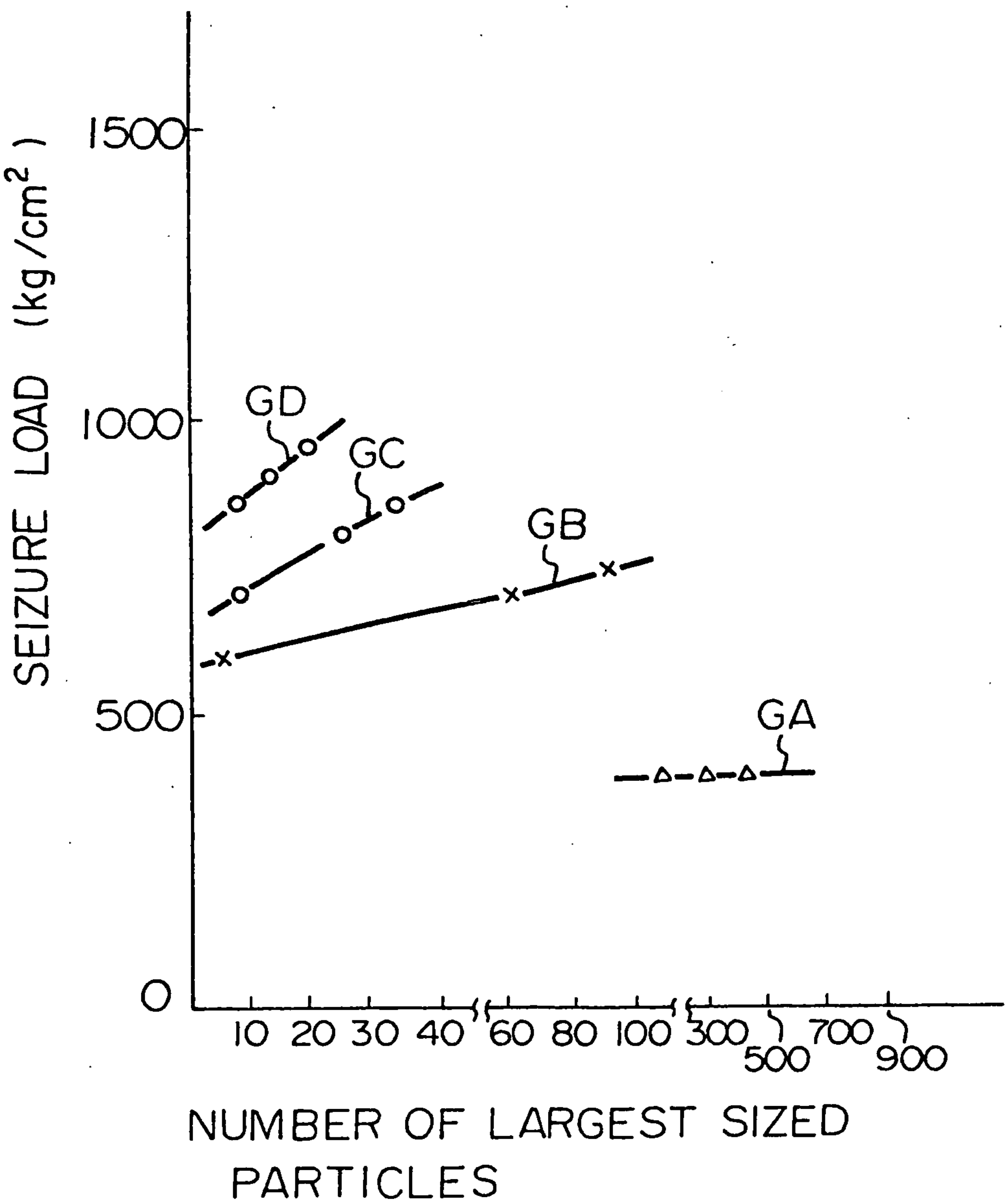

SEIZURE LOAD (kg/cm²)
1500
1000
500
0
GD
GC
GB
GA
10 20 30 40 60 80 100 300 500 700 900
NUMBER OF LARGEST SIZED PARTICLES

Fig. 49

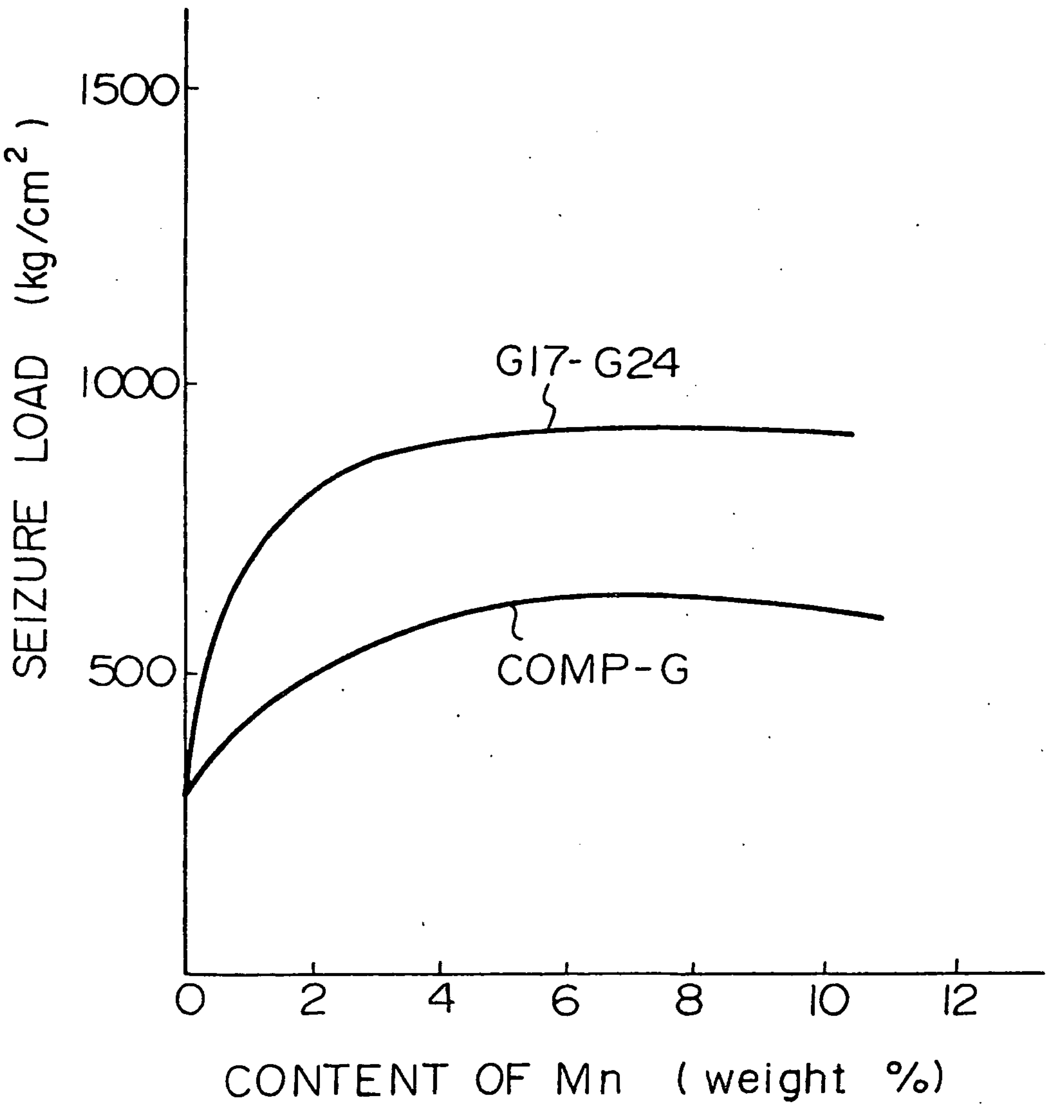

SEIZURE LOAD (kg/cm²)
1500
1000
500
G17-G24
COMP-G
0
2
4
6
8
10
12
CONTENT OF Mn (weight %)

Fig. 50

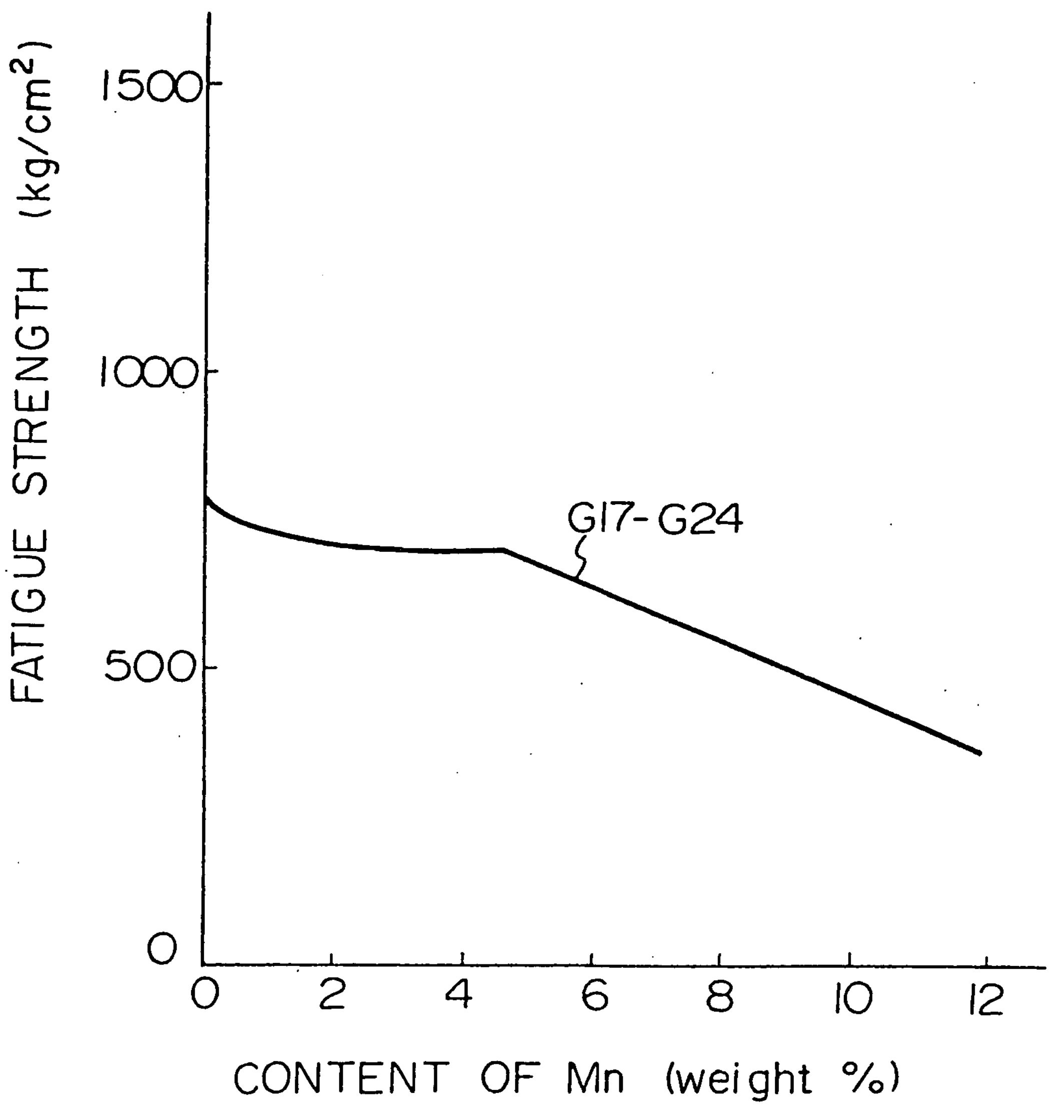
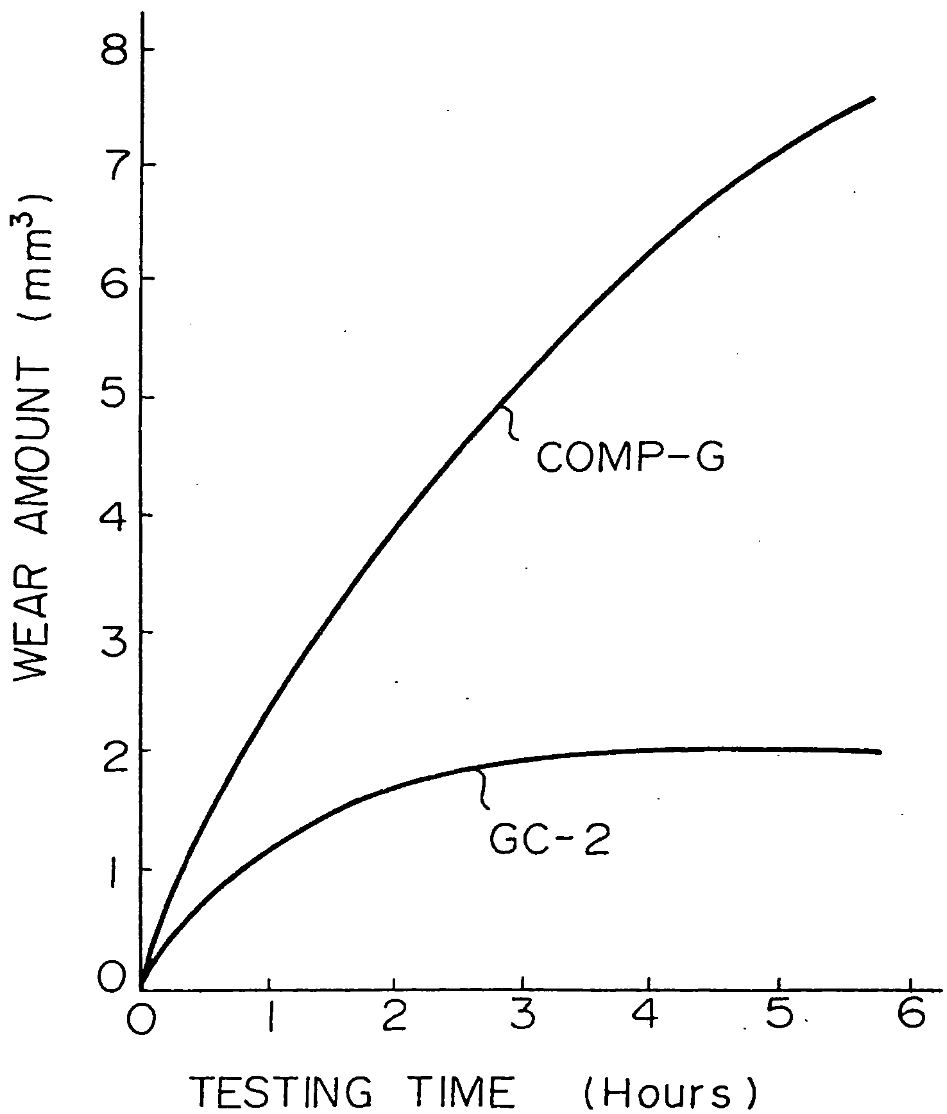
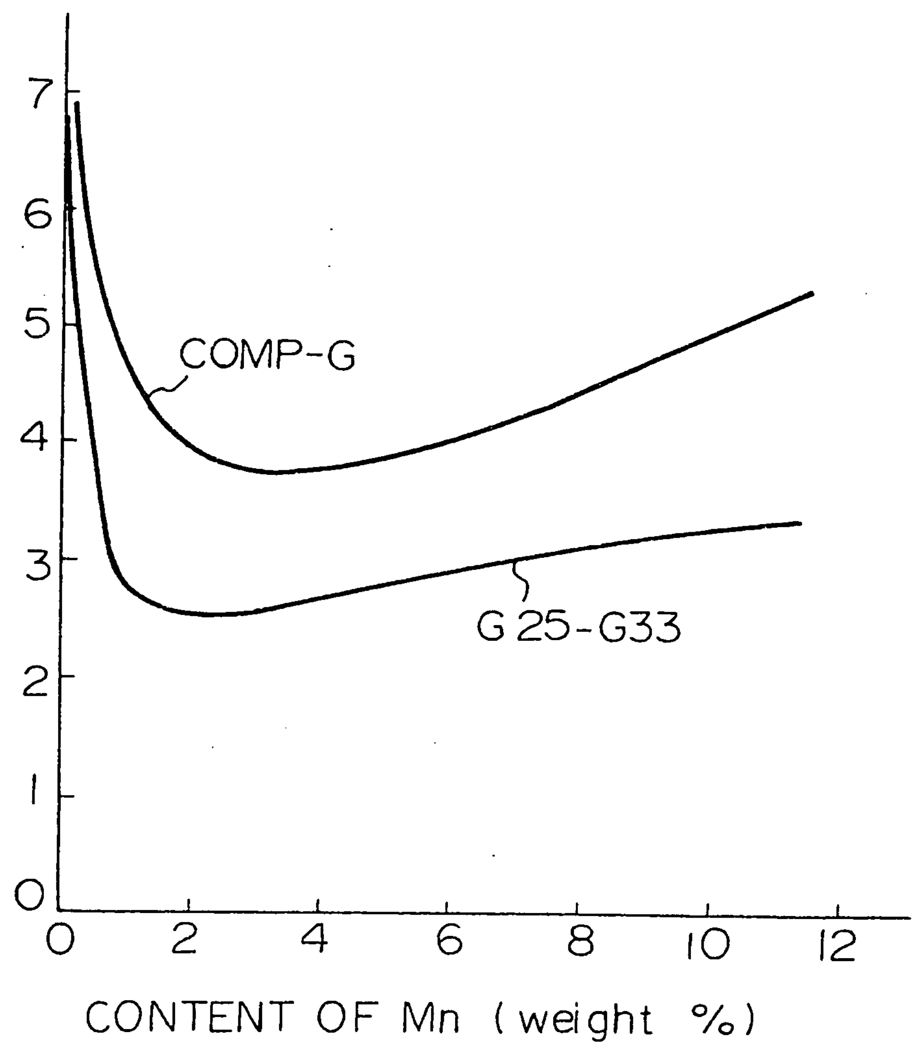

FATIGUE STRENGTH (kg/cm²)
1500
1000
500
0
G17-G24
0
2
4
6
8
10
12
CONTENT OF Mn (weight %)

Fig. 51



8
7
6
5
4
3
2
1
0
WEAR AMOUNT (mm³)
COMP-G
GC-2
0
1
2
3
4
5
6
TESTING TIME (Hours)

Fig. 52



SPECIFICATION

An aluminum-base all y bearing

TECHNICAL FIELD

The present invention relates to an aluminum-base alloy bearing. More particularly, the present invention relates to an improvement in an aluminum-base alloy bearing used in an internal-combustion engine and which occasionally contains tin and/or lead.

BACKGROUND TECHNIQUE

Aluminum alloys are widely used as bearings in internal-combustion engines, e.g., as connecting rod bearings and crankshaft bearings in automobile and marine engines. These bearings are resistant to corrosion in the engine environment and thus are highly advantageous for such use.

Materials employed as bearings in internal-combustion engines are required to withstand high loads and high temperatures. Much effort has been directed in recent years, therefore, to providing aluminum-base bearing alloys having high resistance to seizure, fatigue, and wear under the conditions encountered in these engines.

U.S. Patent No. 4,153,756 discloses Al-Sn base-bearing alloys having a low degree of softening and, consequently, a high fatigue strength under high-temperature conditions. The alloy is provided by adding chromium or zirconium to a basic alloy consisting of from 10 to 30 wt.% of tin, and the remainder being aluminum. Copper or both copper and beryllium can also be added to the alloy.

Al-Sn-base bearing alloys comprising from 3.5 to 35 wt.% of Sn, from 0.1 to 1.0 wt.% of Cr, and from 1 to 10 wt.% in total of one or more members selected from Si, Cr, Mn, Sb, Ti, Zr, Ni, and Fe, the remainder being aluminum, are also disclosed in the prior art as having a high fatigue strength and, additionally, a good wear resistance.

An aluminum-base alloy bearing of the type described above ordinarily has a structure comprising a tin and/or lead containing aluminum-base alloy pressure-welded to a backing steel plate. In order to increase the welding strength between the tin-containing aluminum-base alloy and the backing steel plate, it is indispensable to anneal the welded assembly after pressure-welding. This annealing operation is ordinarily carried out for a long period of time at a temperature lower than the temperature forming an Al-Fe intermetallic compound. However, if the tin and/or lead-containing aluminum alloy is exposed to such a high temperature at the above annealing step, aluminum crystal grains and tin precipitates are coarsened in the alloy structure, resulting in a reduction of the high temperature hardness and fatigue-resistant strength, which are required for a bearing alloy. In order to eliminate the above defects of the tin and/or lead-containing aluminum alloy, there has been used an aluminum bearing alloy comprising an additive element. For example, a tin-containing aluminum-alloy comprising from 3.5% to 4.5% of Sn, from 3.5% to 4.5% of Si, and from 0.7% to 1.3% of Cu with the balance being Al, a tin-containing aluminum alloy comprising from 4% to 8% of Sn, from 1% to 2% of Si, from 0.1% to 2% of Cu and from 0.1% to 1% of Ni with the balance being Al, a tin-containing aluminum alloy comprising from 3% to 40% of Sn, from 0.1% to 5% of Pb, from 0.2% to 2% of Cu, from 0.1% to 3% of Sb, from 0.2% to 3% of Sb, from 0.2% to 3% of Si and from 0.01% to 1% of Ti with the balance being Al, a tin-containing aluminum alloy comprising from 15% to 30% of Sn and from 0.5 to 2% of Cu, with the balance being Al, and a tin-containing aluminum alloy comprising from 1% to 23% of Sn, from 1.5% to 9% of Pb, from 0.3% to 3% of Cu, and from 1% to 8% of Si, the balance being Al (hereinafter referred to as "multicomponent-system bearing alloys") have been used for vehicles and the like.

Recently, a decrease of the size and an increase of the output are required in internal-combustion engines for automobiles. Furthermore, the attachment of an apparatus for reducing a blow-by gas is required for purging the exhaust gas. Therefore, the conditions under which bearings are used have become severe. More specifically, the size of bearings has recently been decreased and bearings now are used under a higher load and higher temperature conditions than in the past. Accordingly, fatigue fracture and abnormal abrasion readily occur in conventional multicomponent-system bearing alloys and problem arise in internal-combustion engines for automobiles due to these undesirable phenomena. In metal materials, a fatigue phenomenon ordinarily takes place when the materials are used over a long period of time, but in recent internal-combustion engines, fatigue fracture of multi component-system bearing alloys sometimes occurs even when a high load operation is conducted for a relatively short time. The temperature of the lubricating oil in an internal-combustion engine is increased at a high load operation. For example, the temperature measured with respect to the lubricating oil in an oil pan is elevated to 130°C to 150°C, and it is therefore presumed that the bearing has a sliding contact with an opposite member, for example, a crankshaft, at a relatively high temperature. In conventional multicomponent-system bearing alloys, the high temperature hardness is drastically reduced by this sliding contact at high temperatures, and melting or migration of the tin phase occurs in the multicomponent-system bearing alloys. The fatigue-resistant strength is reduced in multicomponent-system bearing alloys because of the reduction of the high temperature hardness and melting or migration of the tin phase.

The present applicant proposed in Japanese Patent Application No. 55—851 an aluminum-base alloy comprising from 2.5% to 25% by weight of tin, from 0.5% to 8% by weight of zinc, and from 0.1%

to less than 1% by weight of chromium.

The present applicant proposed in Japanese Patent Application No. 55—852 an aluminum-base alloy comprising from 2.5% to 25% by weight of tin, from 0.5% to 8% by weight of zinc, and from 1% to 7% by weight of at least one element selected from the group consisting of silicon, chromium, manganese, nickel, iron, zirconium, molybdenum, cobalt, tungsten, titanium, antimony, niobium, vanadium, cerium, barium, and calcium, the balance being substantially aluminum.

In these aluminum-base alloys, silicon, chromium, and the like are dispersed in the matrix in the form of a very fine and hard Al-Cr intermetallic compound mainly have the effect of preventing coarsening of tin particles. Most of the zinc is dissolved in the aluminum matrix as a solid solution. The aluminum matrix is reinforced by zinc, and the high-temperature hardness and fatigue-resistant strength can be enhanced. In these aluminum-base alloys, the bearing characteristics of the aluminum alloy are remarkably improved, by the synergistic effects of reinforcement of the matrix and reinforcement of the alloy by finely dispersed precipitated elements, over the bearing characteristics attained by either of these two reinforcements separately.

Incidentally, conformability is one of the characteristics of a bearing. In the above Japanese Patent Applications, the term "conformability" means that the bearing has such a property that the fine convexities and concavities of a shaft, as an opposite member of the bearing, which are formed more or less according to the processing precision are leveled by the embedding action of the bearing. That is, at the initial stage of use of the bearing, the surface of the bearing is shaved off so that both the bearing and the shaft are always kept in contact with each other in the state where a film of lubricating oil is always present between the leveled surface of the shaft and the shaved surface of the bearing. Soft tin particles in the alloy are considered to realize an excellent conformability. The above-described meaning of conformability is established in this technical field. Therefore, the concept of the above-mentioned Japanese Patent Applications, i.e., the provision of conformability due to soft tin particles, conforms to the conventional idea in this technical field and can be said to be a continuation thereof. In addition, in the above-mentioned Japanese Patent Applications, with regard to the effects of chromium, silicon, and the like, these element are considered to suppress the coarsening of tin particles since only the shape of the soft tin particles is controlled, thereby indirectly improving the conformability of the tin-containing aluminum base alloy and no technical concept that particles of chromium, silicon, and the like directly improve the conformability is involved.

In a paper entitled "Aluminum-Based Crankshaft Bearings for the High Speed Diesel Engine", SAE Technical Paper Series, published February 23—27, 1981, in Detroit, the seizure load of an Al-11% Si-1% Cu alloy is reported. According to this report, when silicon particles 17 microns in size are present 8.7×10^{16} per unit area (m^2), the seizure load is dispersed. In addition, when silicon particles 1 micron or more in size are present 0.6×10^6 per unit area, the seizure load is high and the dispersion is small. According to these description and theoretical explanations in the SAE paper hard silicon particles which are finely dispersed in the aluminum matrix contribute to the compatibility of and enhancement of the seizure load. In addition conformability, is mentioned in the SAE paper in a case in which misalignment between a crankshaft and a bearing is tolerated and is contrary to the concept of compatibility.

The mere inclusion of silicon in an aluminum-base bearing alloy, however, does not ensure that the bearing alloy will possess a consistently superior resistance to seizure, fatigue, and wear under the severe loads and temperature conditions encountered in modern internal-combustion engines and, particularly, in automobile engines which have shafts made of spheroidal or nodular graphite cast iron or other coarse material.

DISCLOSURE OF THE INVENTION

The present invention is based on a theory which is completely different from the conventional one and provides an aluminum-base alloy bearing having a conformability and seizure load which are tremendously improved over the conventional ones and which can be used without an overlay.

It is known that since the silicon particles in the aluminum-base alloy are hard they directly polish the mating member, a crankshaft made of steel and thus exert an influence on the conformability or the compatibility.

The theory of uniformly dispersing hard particles in a soft matrix, has been applied for controlling particle size. Such a theory is well known in the field of sliding materials and is also included in the above-mentioned prior Japanese Patent Applications filed by the present applicant.

The present inventors investigated in detail the bearing characteristics of aluminum-base alloys, discovered that by a technical concept and technical measure which are completely different from the conventional ones the bearing characteristics, especially the conformability and the seizure resistance, can be tremendously improved, and then completed the present invention. The technical measure described in detail later, is to control the size of hard particles, such as silicon particles and the like, in the aluminum alloys. In this regard, it is well known that silicon particles crystallize or precipitate (the term "crystallize" is hereinafter used) in a Si-Al binary alloy. In addition, technical papers or patents in which the distribution of silicon particles in aluminum-base alloy bearings used in an internal-combustion engine is discussed have been published.

Japanese Unexamined Patent Publication No. 55—82756 discloses an invention in which, during the production of a bearing alloy, an aluminum-base alloy containing from 5% to 15% of silicon, up to 5% of copper, up to 10% of bismuth and up to 1% of lead is hot- or cold-rolled or extruded so as to obtain at least a 90% of reduction ratio in regard to area and thus to impart to the silicon particles in the alloy not a continuous skelton-like net structure but a finely divided state. This bearing alloy is allegedly useful as both a bearing with a soft plating layer (an overlay) and a bearing without an overlay. The essence of the invention in the Japanese unexamined patent publication mentioned above is that coarse silicon particles in the cast state are finely divided by rolling and the like, and, further, that annealing, which is carried out after rolling if necessary, is carried out only to such an extent that the deformed structure is restored, thereby maintaining the fine shape of the silicon particles. In addition, since a high silicon content of approximately 10% is preferred according to a specific description in this application, the significance of this invention is that the finely divide silicon particles grow coarse in an aluminum alloy having a high silicon content.

According to a discovery made by the present inventors, an aluminum alloy having a high silicon content is disadvantageous for use as an overlay-free bearing alloy of an internal-combustion engine because the fatigue strength is low and fatigue fracture occurs, especially when a bearing slides when subjected to an alternating load from a shaft. If fatigue fracture occurs the load capacity is considerably lowered.

According to another discovery made by the present inventors, the bearing characteristics are not satisfactory enhanced by finely dividing the silicon particles or by for example, rolling a conventional cast article to provide them with a predetermined dimension. The bearing characteristics are extremely enhanced by coarsening the finely divided silicon particles and thus controlling the silicon particles, thereby providing a predetermined size and a predetermined number thereof.

Incidentally, in the above-mentioned Japanese unexamined patent publications, an 11% Si-containing aluminum alloy was tested, and the size of silicon particles was disclosed being from 0.0001 inch (2.5 microns) to 0.001 inch (25 microns). However, the number of silicon particles per unit area was not mentioned at all.

The present invention provides an aluminum-base alloy bearing in which an aluminum alloy is bonded to a backing metal, and the aluminum alloy contains from 0.5% to 11% by weight of at least one hard element selected from the group consisting of silicon, manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium, and at least five particles consisting of or comprising a hard element from 5 microns to 40 microns in size, the size being measured by the length thereof, are present per 3.56×10^{-2} mm^2 in an optional portion of the alloy.

The alloy according to the present invention may comprise as an optional element(s) any combination of: (a) from 1% to 35% of tin; (b) from 0.1% to 10% of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth; and, (c) from 0.1% to 2% of at least one element selected from the group consisting of copper and magnesium. For example:

1. Hard element:
   from 0.5% to less than 5% of silicon
   Optional elements:
   Copper and magnesium
2. Hard element:
   from 0.5% to less than 5% of silicon
   Soft element:
   tin
   Optional elements:
   lead and the like, copper, and magnesium
3. Hard element:
   from 0.5% to less than 5% of silicon
   Soft element:
   lead and the like
4. Hard element:
   from 5% to 11% of silicon
   Soft element:
   tin
   Optional elements:
   lead and the like, copper, and magnesium
5. Hard element:
   from 5% to 11% of silicon
   Soft element:
   lead and the like
   Optional elements:
   tin, copper, and magnesium

6. Hard element(s):
   other than silicon
   Soft element:
   lead
   Optional elements:
   tin, copper, and magnesium

First, the hard particles are explained.

According to a discovery made by the present inventors, when the lengthwise diameter (hereinafter referred to as the size) of the hard particles is 5 microns or more, a special conformability is created which tremendously increases the bearing characteristics of aluminum alloys. This special conformability is appreciable when at least five hard particles 5 microns or more in size are present per 3.56×10^{-2} mm^2, and the special conformability becomes more appreciable as the size of the hard particles becomes greater. When the size of hard particles exceeds 40 microns, the fatigue strength of the aluminum alloy is decreased.

In the present invention, only coarse hard particles, i.e. 5 microns or more hard particles, are the constitution of the invention, and since fine hard particles do not contribute to improvement of the bearing characteristics. This is concept different from the conventional ones namely, in the prior Japanese Patent Application filed by the present applicant, it is disclosed that fine particles control the shape of tin and/or lead particles and indirectly improve the bearing characteristics. Also, according to the theory and experimental data disclosed in the SAE paper, the bearing characteristics improve as the silicon particles become finer. Contrary to this, in the present invention, the bearing characteristics, except for the fatigue resistance, can be markedly improved by making the hard particles coarse. The hard particles according to the present invention are believed to have the ability to flatten the minute unevenness which is generated on a shaft as a result of the accuracy with which the shaft is machined and also to have the ability to lap the nodular cast iron of a shaft and thus flatten the surface of nodular cast iron around the hollows which are formed due to the falling out of the graphite particles. As a result of the flattening mentioned above, an oil film is constantly formed between the bearing and shaft, thus ensuring a good sliding of the bearing and shaft. The ability of the hard particles to directly flatten the unevenness of the opposed member is a type of conformability. This is referred to as a special conformability in order to distinguish it from the conformability according to a conventional concept in the field of bearings, in which field it is believed that a soft element, such as tin, the ability has to create conformability.

The special conformability, which can markedly enhance the bearing characteristics, especially the seizure load, as compared with those attained only by the conformability according to the conventional concept, is one of the features of the present invention. Incidentally, the alloys according to the present invention may contain tin and/or lead, and thus may have the conformability according to the conventional concept. It is believed that the special conformability is first realized, and thus the opposed member is flattened, and that the conformability according to the conventional concept is subsequently realized, and thus soft metal is embedded in the surface of the opposed member. Since such alloys exhibit both the special conformability and the conformability according to the conventional concept, the characteristics of a bearing used in an internal-combustion engine are extremely improved over those of conventional bearings due to a combination of these two types of conformabilities.

Silicon is an element which brings about the special conformability. If the silicon content is less than 0.5%, the silicon is not effective for attaining the special conformability. If the silicon content is 5% or more, the fatigue strength and the seizure load tend to decrease. The silicon content can however, be up to 11%. A preferable silicon content which can wear out the shaft is from 2% to less than 5%.

Hard elements other than silicon, i.e., manganese, iron, molybdenum, nickel, zirconium, cobalt, antimony, chromium, and niobium, bring about the special conformability. When hard elements other than silicon are collectively mentioned, they are referred to as manganese and the like. If the content of the manganese and the like is less than 0.5%, the manganese and the like are not effective for attaining the special conformability. If the content of the manganese and the like is more than 11%, the special conformability is not enhanced and the fatigue strength and the seizure load tend to decrease. A preferable content of the manganese and the like is from 1% to 9%. When two or more of the manganese and the like are added to an aluminum alloy, the minimum content of each of the manganese and the like is preferably 0.1%.

The particles which are formed by the addition of the manganese and the like are now described.

It is impossible to analyze the component of crystals as to whether the manganese and the like crystallize as a metal form alone or crystallize as an intermetallic compound, in which aluminum and the manganese and the like are combined. Since the hard particles, which are different from soft particles, such as tin particles, are formed due to the addition of the manganese and the like in the tin-containing aluminum alloy, the particles which crystallize consist of or comprise the manganese and the like.

The special conformability described above is particularly useful for enhancing the seizure resistance when the opposed member or shaft is made of nodular graphite cast iron or flake graphite cast iron.

The effects of hard particles are described in detail regarding how the special conformability is attained when the opposed member is made of nodular graphite cast iron or flake graphite cast iron.

A nodular graphite cast iron shaft is often used in of an internal-combustion engine instead of a conventional forged shaft because of the low cost thereof. During polishing of such a shaft, the graphite particles are shaved off of the surface of the shaft, and a number of concavities or holes are formed. The iron-base matrix around such concavities or the like is work-hardened, and sharp burrs and edges are formed around such concavities. These burrs and the like result in abnormal wear of conventional aluminum alloys for use as a bearing, according to the results of research made by the present inventors regarding abnormal wear, the soft aluminum matrix is shaved off by the burrs and the like and settles in the concavities. And since the settled aluminum and the aluminum alloy of the bearing are very likely to adhere to each other due to poor compatibility, seizure readily occurs. In accordance with the present invention, coarse hard particles shave off the burrs and the like and flatten the circumferential portions of the concavities, with the result that seizure does not occur until the load is increased to a high level, that is the seizure resistance is tremendously enhanced.

A method for controlling the size and number of hard particles is now described. Generally, most of the silicon crystallizes as acicular eutectic crystals in the step of casting the Al-Si alloy. When the cast alloy is rolled so as to provide it with a thickness necessary for use as a bearing, the acicular eutectic crystals are cut into small pieces. The Al-Si alloy thin sheet obtained by the casting and rolling process includes silicon particles having an acicular and flat shape, most of the particles being 5 microns or less in size, particles 10 microns or more in size being rare and their number per unit area being small.

After the rolling an intermediate annealing is carried out at a temperature which approximately equal to the recrystallization temperature. Coarsening of the silicon particles virtually does not take place at the intermediate annealing temperature.

After the above-described casting, rollings, intermediate annealing are carried out to produce a bearing alloy having a predetermined thickness, it is pressure-welded to a backing steel plate and is then annealed at a temperature less than the formation temperature of Al-Sn intermetallic compound, e.g., at a temperature of 350°C, according to a conventional process. Coarsening of the silicon particles does not virtually occur even at a temperature of 350°C, with the result that the fine silicon particles, most of which having less than 5 microns in size, are present in the final product. When the bearing alloy is subjected to a high-temperature heat treatment of from 350°C to 550°C before being pressure-welded, coarsening of the hard particles takes place. The high-temperature heat treatment before the pressure welding is very effective for obtaining at least five particles 5 microns to 40 microns in size per 3.56×10^{-2} mm². Contrary to this, the heat treatment other than that before the pressure welding is not very effective. It is extremely difficult to control the size of the hard particles, during a step other than the heat-treatment step before the pressure-bonding, for example, during a rolling step, in which the heating temperature and draft can be controlled, a casting step in which the cooling rate can be controlled, or an intermediate annealing step. When the high-temperature heat treatment is carried out during or after pressure-welding, Al-Fe intermetallic compounds form or a low-melting point component, such as tin, melts in the aluminum alloy directly before the completion of a bearing. This is disadvantageous in respect to the bearing characteristics, especially the conformability according to the general concept thereof.

Judging from phase diagrams, the hard particles of binary alloys, such as Al-Mn alloy and the like, are believed to be of the following kinds depending upon the kinds of an alloying elements:

Mn : $MnAl_4$ and $MnAl_6$

Fe : $FeAl_3$

Mo : $MoAl_3$

Ni : $NiAl_3$

Zr : $ZrAl_3$

Co : Co_2Al_9

Ti : $TiAl_3$

Sb : AlSb

Nb : $NbAl_3$

The crystals which are considered to be the intermetallic compounds listed above precipitate in various forms during casting. The shape of these crystals is also controlled as was described above.

Table 1 below illustrates how the number of hard particles crystallized due to the high-temperature heat treatment prior to pressure-welding varies in accordance with the content of a hard element. Table 1 was complied from a calculation based on the presumption that a hard element entirely crystallizes as cubic hard particles having the sizes given in the top horizontal column.

The majority of hard particles less than 5 microns in size coarsen and become 5 microns or more in size due to the high-temperature heat treatment. Therefore, Table 1 is a useful reference for controlling the size of hard particles in the aluminum alloy according to the present invention.

TABLE 1

Calculated Number of Hard Particles

(Number per $3.56 \times 10^{-2} mm^2$)

Content of Hard Element (wt%) \ Particle Size (μ)	5	10	20	30	40
0.5	340	40	5	1	0
1	680	80	10	3	1
3	2000	260	30	9	4
5	3500	430	50	15	6

When the content of a hard element is 0.5%, the number of hard particles 5 microns in size is 340. Therefore, even if part of the hard particles crystallized are less than 5 microns in size, at least five hard particles 5 microns in size can assuredly be obtained. Number of hard particles 5 microns in size varies from 340 to 3500 depending upon the content of hard element, according to Table 1.

The number of hard particles from 5 to 10 microns in size, in the bearing alloy is actually less than 340 to 3500 which is the number of hard particles given in Table 1 and which varies depending upon the content of the hard element.

It should be noted that although fine hard particles less than 5 microns in size may crystallize, the proportion of coarse particles 5 microns or more in size to fine particles less than 5 microns in size can be increased by a high-temperature heat treatment carried out at for example, from 350°C to 450°C.

When the content of a hard element is 3%, the number of hard particles is four, provided that all of the hard element crystallizes as hard particles 40 microns in size. If only one hard particle 40 microns in size crystallizes, 5—30 micron hard particles can additionally crystallize.

The following four examples illustrates the preferred number of coarse hard particles ranging from 5 to 40 microns in size and which crystallize when the content of the hard element varies in the range of the present invention.

EXAMPLES:

1. number of hard particles greater than 4 microns in size: 5 or more
2. number of hard particles 20 microns or more in size (17 microns or more in size when the silicon content is 5% or more): 2 or more
3. number of hard particles 30 microns or more in size: 1 or more
4. number of hard particles from 20 to 40 microns in size: 5 or more

The shape of the hard particles according to the present invention is now described.

Usually, the hard particles are acicular in the rolled aluminum alloy and their axis is in agreement with the rolling longitudinal direction in many cases. However, due to the high-temperature heat treatment according to the present invention, the width of the hard particles is relatively increased as seen in the traversal direction of the rolling direction, and the hard particles become nodular. As seen in the horizontal plane of a bearing, i.e., the surface of a bearing in contact with a shaft, the hard particles exhibit a nodular shape. A preferable shape of the hard particles is a nodular shape as seen in the horizontal plane and vertical plane. Most of the hard particles of 5 microns or more in size are nodular, and flat hard particles are few in number. There are almost no acicular hard particles per the predetermined area. These nodular hard particles are extremely useful for realizing the special conformability.

The structure of the above-mentioned horizontal plane the aluminum-base alloy first observed and

then the hard particles are measured so as to determine the size thereof. In order to distinguish the silicon particles from the other particles, such as chromium-intermetallic compound particles and tin phases in the alloy, the following standard may be used. That is, when observed with a metal microscope, chromium and tin appear white, and the hard particles appear gray or dark gray no matter which etching method is used.

The area of 3.56×10^{-2} (mm)^2 is chosen for convenience and is based on the viewing area of the microphotography equipment of the inventors. The number of Si particles per unit area can be modified by employing appropriate conversion factors. For example, the above-described particle number/area limitation corresponds to 1.4×10^8 particles per m^2. The number of particles per cross sectional area of the bearing alloy is that determined in a horizontal cross section of a sheet of the alloy, i.e., a cross section that is parallel to the surface of the sheet (and viewed in a direction perpendicular to the surface thereof), when prepared according to a process described below. The size of the Si particles measured in a vertical cross section of a sheet of the alloy is smaller than that measured in a horizontal cross section. Further the quantity limitations described above may not be fulfilled on the surface of a sheet of the alloy directly after its machining.

The optional elements are now described.

Tin renders an aluminum alloy soft and imparts a lubricating property and conformability suitable for a bearing to the aluminum alloy. The term "conformability" is defined by the technical concept generally accepted in the pertinent art and is referred to as the conformability according to the conventional concept.

If the content of tin exceeds 35% both the conformability according to the conventional concept and lubricating property of the aluminum alloy are improved but the hardness and strength thereof become too low for the alloy to be used as a bearing. On the other hand, if the tin content is less than 1%, the conformability according to the conventional concept is reduced. The amount of tin added is appropriately selected within the range of from 1% to 35% by weight according to the intended use of the bearing but ordinarily, as the load imposed on the bearing is high, that is, when the explosion load imposed on the bearing through a piston of the internal-combustion engine is high, the tin content is preferably controlled to a low level, for example, from 5% to 10%, and when the load imposed on the bearing is low, the tin content is preferably increased. When there is a risk of seizure of a bearing due to a high load and high speed rotation, it is preferred that the tin content be increased to, for example, from 15% to 25% by weight.

Incidentally, in the prior Japanese Patent Application filed by the present applicant, it is deemed that in order to make the fatigue strength and high-temperature hardness of a Sn-containing aluminum alloy satisfactory enough for the alloy to be used as a bearing, the fine dispersion of tin particles in the alloy is crucial. Thus, in the prior patent application, it is proposed to prevent the coarsening of tin particles by the use of fine particles of chromium and the like, coarsening being liable to occur at a tin content exceeding 15%. However, since in the present invention the special conformability is substantially responsible for the bearing characteristics, no great importance is attached to the fine dividing of tin particles and no problems arise in the use of the bearing in an internal-combustion engine. The tin content is preferably from 5% to 25%.

Lead, cadmium, indium, thallium, and bismuth (the term "lead and the like" is used when all of these elements are described) render an aluminum alloy soft and impart a lubricating property and a conformability according to the conventional concept to the aluminum alloy. If the content of the lead and the like exceeds 10%, the conformability according to the conventional concept and the lubricating property are improved but the hardness of the aluminum alloy is decreased. If the content of the lead and the like is less than 0.1%, the aluminum alloy is too hard to be used as a bearing alloy and thus the conformability according to the conventional concept is impaired.

The amount of the lead and the like is appropriately selected within the range of from 0.1% to 10% according to the intended use of the bearing, but ordinarily, as the load imposed on the bearing is high, that is, when the explosion load imposed on the bearing through a piston is high, the content of the lead and the like is preferably controlled to a low level, for example, from 1% to 4%, and when the load imposed on the bearing is low the content of the lead and the like is preferably controlled a high level. When there is a risk of seizure of a bearing due to a high load and a high rotation speed, the content of the lead and the like is preferably controlled to a high level, for example, from 4% to 8%. In order to provide a lead-and/or tin-containing aluminum alloy having a satisfactory fatigue strength and a high-temperature hardness, which factors are necessary for a bearing, the particles of lead and the like should be finely dispersed in the alloy. However, lead is the element which is particularly difficult to finely disperse. Since in the present invention the special conformability is virtually responsible for the bearing characteristics, no great importance is attached to the fine dividing of lead particles and no problems arise in the use of the bearing in an internal-combustion engine. A preferable content of lead and the like is from 1% to 6%. When lead and the like, and chromium are all present in the alloy, the lubricating property is improved without the fatigue strength being deteriorated.

Generally speaking, when lead and the like are alloyed into an Al-Sn binary alloy, they are incorporated into the tin particles. The tin particles, the melting point of which is decreased due to the alloying, are liable to move and melt, with the result that during continuous operation of a bearing under

a high load the Al-Sn-Pb alloy may locally melt and peel off of bearing.

In the present invention, the special conformability greatly contributes to the improvement of a bearing's characteristics, and a decrease in the melting point due to formation f a tin-lead alloy does not result in a serious problem.

Copper and the like enhance the hardness of an aluminum alloy and enhance the fatigue strength of a bearing. When the content of copper and the like is less than 0.1%, they do not effectively enhance the hardness. On the other hand, when the content exceeds 2.0%, the aluminum alloy is too hard and its rolling workability as well as the seizure resistance and the corrosion resistance to lubricating oil deteriorate.

Cu and/or Mg can be contained in the bearing alloy of the present invention in an amount of from 0.1% to 2 wt.%. The hardness of the alloy is increased as the amount of Cu and/or Mg is increased within this range whereas the seizure resistance decreases. Therefore, the amount of Cu and/or Mg employed is chosen so as to obtain a desired balance between the hardness and the seizure resistance of the bearing alloy. An increase in the hardness of the alloy is not obtained with amounts of Cu and/or Mg of less than 0.1 wt.%. Amounts of these metals of more than 2.0 wt.% reduce the rolling property of the bearing alloy and lower the wear resistance and the anti-corrosiveness thereof to the lubricating oil. Furthermore, the Mg exists as a solid solution in the aluminum matrix and is liable to deposit during annealing if the amount thereof is more than 2.0 wt.%.

The addition of from 0.1 to 1 wt.% of Cr and/or Mn to a bearing alloy according to the present invention is also effective in preventing the lowering of the hardness of the alloy at high temperatures (although to a lesser extent than the addition of Cu and/or Mg) and in preventing the coarsening of Sn particles. When the quantity of the Cr and/or Mn is less than 0.1 wt.%, an improvement in the high-temperature hardness cannot be expected. The effect of the addition of amounts of more than 1.0 wt.% is not appreciable. The Cr and/or Mn form fine precipitates in the aluminum matrix. The Cr and/or Mn also serve to enhance the effects of the addition of Cu and/or Mg and of Pb, In, Tl, Cd, and/or Bi.

The chromium and manganese effects of increasing the hardness of an aluminum-base alloy, preventing or mitigating softening of the alloy at a high temperature, and not causing coarsening of the Pb particles and the like are now described in detail. Part of the chromium and manganese is solid-dissolved in the aluminum matrix to bring about solid solution hardening of the aluminum matrix and to elevate the recrystallization temperature, whereby the recrystallization softening temperature is shifted to a higher temperature side. Furthermore, the work hardenability of the aluminum alloy is increased. The function of increasing the recrystallization temperature is especially effective and advantageous because even at a high temperature to which the bearing of an internal-combustion engine is exposed (an oil pan temperature of from 130°C to 150°C), the mechanical characteristics of the bearing alloy can be stably maintained. Especially, the incorporation of chromium and manganese results in improvement of the fatigue strength and the load capacity. Part of the chromium and manganese is solid-dissolved in the aluminum matrix and the remainder of chromium and manganese is finely precipitated in the form of an Al-Cr (Mn) intermetallic compound. This Al-Cr (Mn) intermetallic compound prevents the tin particles from coarsening when the bearing alloy is pressure-welded to a base and annealed or when the bearing alloy is exposed to a high temperature of an internal-combustion engine. The Al-Cr (Mn) intermetallic compound has a Vickers hardness of approximately 370 and is not as hard as silicon particles, which have a Vickers hardness of approximately 1,000. Because of the difference in hardness, it is believed that the Al-Cr (Mn) particles prevent coarsening of the tin particles and realize a conformability according to the conventional concept, while hard particles flatten the unevenness of the opposed member or the shaft and realize a special conformability. At least 0.1% of Cr or Mn is necessary for bringing about the effects mentioned above. If the content of Cr or Mn exceeds 1%, the Cr or Mn crystallizes as a coarse Al-Cr intermetallic compound or the like, which is disadvantageous.

The matrix of the bearing alloy according to the present invention preferably has a Vickers hardness of from 30 to 60 Hv. When the matrix of an aluminum alloy is very soft, the load capacity of the bearing is insufficient and when a load is applied to the bearing, the silicon particles are pushed into the surface. If the aluminum matrix is too hard, when a shaft contacts the bearing surface, the silicon particles may be removed from the surface and will not become embedded again but will roll between the shaft and the bearing and cause excessive wear.

The bearing alloy described above has a thickness of from 0.1 to 1 mm, preferably from 0.2 to 0.5 mm. If necessary, rust-proof oil can be applied on the bearing alloy.

The aluminum-base bearing alloy according to the present invention is prepared by melting aluminum in a gas furnace and adding desired amounts of Si and Sn and, depending on the desired properties of the alloy, optional elements such as Pb, In, Cu, Cr, and the like to the molten aluminum according to conventional techniques. The molten alloy is cast and the cast alloy is then subjected to the steps of peeling, repeated (if necessary) rolling and annealing to obtain a sheet of the alloy of a desired thickness, slitting, annealing, sanding, and brushing and the like to obtain bearing alloy pieces. These pieces are then applied to backing steel sheets by conventional pressure-welding techniques to obtain bimetal pieces, which are subjected to annealing and coiling. These annealed pieces can then be worked into plain bearings. The foregoing steps employed in the process of the present invention are,

per se, known in the art relating to the preparation of aluminum base bearings and are disclosed, for example, in United States Patent Nos. 3,078,563, 3,093,885, 3,104,135, 3,167,404, 3,300,836, 3,300,838, and 3,384,950. The processes for preparing aluminum base bearings disclosed in these patents are incorporated herein by reference.

Control of the size and number of nodular silicon particles in the bearing alloy which meet the limitations described above, i.e., at least five particles having a size of at least 5 microns, may be obtained by controlled annealing of the cast alloy according to conditions not previously disclosed in the art. Specifically, in the process employed in the present invention, during the rolling and annealing of the cast alloy, annealing is carried out at a temperature of from 280°C to 550°C for from one and half to six hours. Following slitting, annealing is carried out at a temperature greater than 350°C and up to 550°C for from one and half to six hours followed by controlled cooling at a rate of less than 200°C per hour. Following bonding to the backing steel by pressure-welding, annealing is carried out at a temperature of from 300°C to 400°C for from 1 to two hours.

As was noted previously, the aluminum-base bearing composite according to the present invention is prepared by pressure-welding the aluminum-base bearing alloy according to the present invention to a backing steel according to conventional techniques and annealing the resultant composite at a temperature of from 300°C to 400°C for from one to two hours. The aluminum-base bearing composite according to the present invention can be used as a bearing for internal-combustion engines under the conditions of a high load without the need for a lead overlayer or overplate, which is required for conventional aluminum base bearings.

TABLE 2

	Step	Prior Art Process(es)	Process Employed in Present Invention
(1)	Dissolution	Melting at 670—750°C	←
(2)	Casting	1.5—2.5 m/min (1—2 m/min)	←
(3)	Peeling	Reduce thickness about 2 mm	←
(4)	Rolling	2—6 mm/pass	←
(5)	Annealing	180—230°C for about 1.5 hours (≤350°C for about 1.5 hours)	280—550°C for 1.5 to 6 hours
		Steps (4) and (5) repeated, if necessary	
(6)	Rolling	2—6 mm/pass	←
(7)	Slitting	No conditions specified	←
(8)	Annealing	180—230°C for about 1.5 hours No control of cooling speed (≤350°C for about 1.5 hours No control of cooling speed)	Greater than 350°C—550°C for 1.5 to 6 hours Cooling speed: less than 200°C/hour
(9)	Sanding	0.01—0.05 mm	←
(10)	Brushing	No conditions specified	←
(11)	Pre-heating	100—180°C (60—140°C)	←
(12)	Sanding	0.005—0.05 mm	←
(13)	Cleaning	Trichloroethylene	←
(14)	Ni-plating	Thickness <5 μm	←
(15)	Pre-heating	80—230°C	←
(16)	Bonding (Pressure welding)	Reduction ratio: 45—55% (45—60%)	←
(17)	Annealing	180—230°C for about 1.5 hours (≤350°C for about 1.5 hours)	300—400°C for 1—2 hours
(18)	Coiling	No conditions specified	←

Note: (1) Conditions in parentheses are isolated teachings in the prior art.
(2) Steps (12)—(15) apply to the backing steel to which the alloy is bonded in step (16).

The present invention may be better understood from the following description made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 through 3 show the results of testing of Al-Si base alloys.

Fig. 1 is a graph showing the seizure loads of Al-Si-1 weight % Cu alloys according to the present invention as a function of the Si content of the alloys.

Fig. 2 is a graph showing the fatigue loads versus the silicon content of an alloy according to the present invention.

Fig. 3 is a graph showing a comparison of the wear resistance versus the Si content of aluminum-base bearing alloys according to the present invention with that of Al-Si%-1% Cu alloys in which the size of the silicon particles is less than 5 microns.

Fig. 4 through 17 show the results of testing of Al-Si-Sn-Pb base alloys.

Fig. 4 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 5 is a graph showing seizure loads as a function of the surface roughness of a shaft.

Fig. 6 is a graph showing seizure loads as a function of the Si content.

Fig. 7 is a graph showing seizure loads as a function of the oil temperature.

Fig. 8 is a graph showing how the seizure load varies in accordance with the content of soft metal.

Fig. 9 is a graph showing the fatigue load as a function of the largest-sized silicon particles.

Fig. 10 is a graph showing a time change in the amount of wear.

Fig. 11 is a graph showing a change in the shaft roughness as a function of the number of the largest-sized silicon particles.

Fig. 12 is a graph showing the seizure load as a function of the silicon content.

Fig. 13 is a graph showing the amount of wear as a function of the silicon content.

Figs. 14 through 17 are microscopic photographs of aluminum-alloy samples.

Figs. 18 through 23 show the results of testing of Al-Pb-Si base alloys.

Fig. 18 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 19 is a graph showing the seizure load as a function of the silicon content.

Fig. 20 is a graph showing the time change in the amount of wear.

Fig. 21 is a graph showing the seizure load as a function of the silicon content.

Fig. 22 is a graph showing the amount of wear as a function of the silicon content.

Fig. 23 is a sketch of the microscopic structure of an aluminum-alloy sample.

Fig. 24 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 25 is a graph showing the seizure load as a function of the silicon content.

Fig. 26 is a graph showing the fatigue load as a function of the silicon content.

Fig. 27 is a graph showing the amount of wear as a function of the largest-sized silicon particles.

Fig. 28 is a graph showing the variance condition of the seizure load.

Fig. 29 is a graph showing a time change in the amount of wear.

Fig. 30 is a graph showing the seizure load as a function of the silicon content.

Fig. 31 is a graph showing the amount of wear as a function of the silicon content.

Figs. 32 and 33 are sketches the microscopic structure of an aluminum-alloy sample.

Figs. 34 through 38 show the results of testing of an Al-Si-Pb base alloy.

Fig. 34 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 35 is a graph showing the seizure load as a function of the silicon content.

Fig. 36 is a graph showing the fatigue load as a function of the silicon content.

Fig. 37 is a graph showing the amount of wear as a function of the number of the largest-sized silicon particles.

Fig. 38 is a graph showing the time change in the amount of wear.

Figs. 39 through 47 show the results of testing of an Al-Sn-Pb-Mn base alloy.

Fig. 39 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 40 is a graph showing the seizure load as a function of the surface roughness a shaft.

Fig. 41 is a graph showing the seizure load as a function of the Manganese content and the like.

Fig. 42 is a graph showing the fatigue load as a function of the Manganese content and the like.

Fig. 43 is a graph showing the time change in the amount of wear.

Fig. 44 is a graph showing the seizure load as a function Manganese content and the like.

Fig. 45 is a graph showing the amount of wear as a function of the Manganese content and the like.

Figs. 46 and 47 are sketches of the microscope structure of an aluminum-alloy sample.

Figs. 48 through 52 show the results of testing of an Al-Pb-Mn base alloy.

Fig. 48 is a graph showing the seizure load as a function of the number of the largest-sized silicon particles.

Fig. 49 is a graph showing the seizure load as a function of the Manganese content and the like.

Fig. 50 is a graph showing the fatigue load as a function of the Manganese content and the like.

Fig. 51 is a graph showing the time change in the amount of wear.

Fig. 52 is a graph showing the amount of wear as a function of the Manganese content and the like.

BEST MODE FOR CARRYING OUT THE INVENTION

Aluminum-base bearing alloys according to the present invention were prepared by a process as described above under the conditions listed in Table 1, unless otherwise specified. However, when the properties of a bearing alloy were to be tested, the pressure welding step and succeeding steps were omitted.

EXAMPLE 1

Each of the alloys contained, in addition to aluminum, 0.5% wt.% of Cu, and 0.4 wt.% of Cr and Si in the amount listed in Table 3 below. The cooling conditions following annealing were not controlled. The annealing and cooling conditions in step (8) of the process were controlled as listed in Table A so that each of the alloys contained approximately 33 to 38 nodular particles of Si having a size of from 5 to 10 microns, approximately 10 to 13 nodular particles of Si having a size of from 10 to 20 microns, and approximately 2 to 4 nodular particles of Si having a size of from 20 to 40 microns, the balance of the Si particles being less than 5 microns in size.

TABLE 3

		Annealing Condition (Step (8) — Table 1)		
Samples	Si (wt%)	Temperature (°C)	Time (Hr)	Cooling (°C/Hr)
A1	0.5	500	5.0	100
A2	1	475	4.5	120
A3	3	450	4.0	140
A4	4.5	425	3.5	160
A5	7	400	3.0	180
A6	9	375	2.5	190
A7	11	360	2.0	200
A8	13	360	1.5	200
A9	15	360	1.5	200

The seizure resistance of these alloys was tested by using the seizure tester shown in Table 4. For comparison, Al-Si-Cu (1 wt.%) alloys were prepared according to a prior art process such that the Si particles were less than 5 microns in size.

TABLE 4

Tester		Test Conditions
A — Seizure Tester	Rotary disc material:	Nodular
	Disc surface roughness:	1—1.2 μm Rz
	Lubricant:	SAE 10W—30 (1) Kerosene (10)
	Sliding speed:	15 m/sec
	Lubricating:	System pad oiling
	Urging load:	10 kg/cm²/10 min. (increase gradually)
	Bearing surface roughness:	1—1.8 μm Rz
B — Fatigue Tester	Shaft material:	AISI 1055 (forged)
	Lubricant type:	SAE 10W—30
	Shaft surface roughness:	0.8 μm Rz
	Oil temperature:	140°C ± 2.5°C
	Oil pressure:	5 kg/cm²
	Rotation speed:	3,000 rpm
	Shaft diameter:	52 mm
	Shaft hardness:	500—600 Hv
	Stress repetitions:	10^7
	Bearing surface roughness:	1—1.8 μm Rz
	Bearing inner diameter and width:	52 x 20 mm
C— Wear Tester	Shaft material:	Nodular
	Lubricant:	Liquid paraffin
	Shaft surface roughness:	0.8—0.9 μm Rz
	Rotation speed:	100 rpm
	Shaft diameter:	40 mm
	Shaft hardness:	200—300 Hv
	Urging load:	25 kg
	Length of test:	5 hr

The resultant data is shown in Fig. 1.

It may be seen by referring to Fig. 1 that the aluminum-base bearing alloys of the present invention in which the shape, size, and number of silicon particles are controlled have a far better seizure resistance than do similar alloys containing silicon particles less than 5 microns in size.

The fatigue resistance of the alloys of Table 3 was measured according to the conditions for fatique tester B listed in Table 4. The fatigue load data is shown in Fig. 2. As can be seen from Fig. 2, the fatigue resistance of the alloys of the present invention remains relatively constant when the Si content is varied within the range of from 0.5 to 5.0 wt.% but decreases when the Si content is increased more than 5 wt.%.

The wear resistance of the alloys of Table 3 was measured according to the conditions listed for wear tester C in Table 4. The wear data for these alloys is shown in Fig. 3. The wear resistance of the comparative Al-Si-Cu(1) alloys (denoted by COMP—A) having Si particles less than 5 microns in size was similarly determined, and the data is also shown in Fig. 3.

The aluminum-base bearing alloys according to the present invention having controlled Si particle formation can be seen to be markedly superior in wear resistance.

Aluminum-base bearing alloys according to the present invention having the composition Si-3 wt.% Cu-0.5 wt.%, and Cr-0.4 wt.%, the balance being aluminum, were prepared according to the process of the present invention.

TABLE 5

Number of Si Particles/3.56 x 10^{-2} $(mm)^2$

Samples		less than 5 μm	5—10 μm	10<—20 μm	20<—40 μm
	1	98*	0	—	—
AA	2	156*	0	—	—
	3	323*	0	—	—
	1	bal	5	0	—
AB	2	,,	31	0	—
	3	,,	62	0	—
	1	,,	25	6	0
AC	2	,,	19	11	0
	3	,,	21	17	0
	1	,,	16	8	1
AD	2	,,	21	10	4
	3	,,	14	11	8

* Number of Si particles 2.5—<5 μm in size

The annealing conditions in step (8), Table 1, were varied to produce samples A-1 to A-3, B-1 to B-3, C-1 to C-3, and D-1 to D-3 containing the distribution of nodular Si particles set forth in Table 5.

The vickers hardness values of aluminum-base bearing alloys (25°C) containing 3%Si-0.4Cr and approximately 0.1%, 0.5%, 1%, and 1.75% of Cu were approximately 40, 48, 55, and 60 respectively. The annealing conditions employed in the preparation of the alloys (corresponding to step (8) of Table 1) were controlled so that the alloys had a Si particle distribution similar to that of alloy D-2 in Table 3. It is seen that the Cu content has a significant effect on the hardness of the alloys.

The vickers hardness values of aluminum bearing alloys (200°C) containing 3%Si-0.5%Cu and approximately 0.1%, 0.3%, 0.5%, and 1% of Cu were approximately 18, 24, 26.5, and 28.5, respectively. The alloys were prepared in such a manner that their Si particle distribution was similar to that of alloy AD-2 in Table 5. It is apparent that the Cr and Cu contents of the alloys influence the hardness of the alloys although the effect of Cr on the hardness of the alloys is not as great as that of Cu.

To demonstrate the outstanding seizure and fatigue resistance of the aluminum-base bearing alloys according to the present invention having different Si contents, bearing alloys having a Cu content of 0.5 wt.%, a Cr content of 0.4 wt.%, and a Si content as shown in Table 6, the balance being Al, were prepared according to the process described above and under the conditions of the process employed in the present invention listed in Table 1. The annealing conditions (step (8), Table 1) were varied to produce nodular Si particles having the number and size distribution listed in Table 6.

The data of Table 6 demonstrates that for each Si content, the seizure resistance of the alloy is increased as the number and size of the Si particles increase whereas the fatigue resistance is decreased slightly for bearing alloys containing larger Si particles.

TABLE 6

Samples	Si (wt.%)	Si Particles 3.56 x 10^2 $(mm)^2$				Seizure Load (Seizure Tester A) (kg/cm²)	Fatigue Load (Fatigue Tester B) (kg/cm²)
		<5 μm	5—10 μm	10<—20 μm	20<—40 ‡m		
AA—1	0.5	Bal	0	0	0	20	900
AA—2	"	"	2	0	0	30	900
AA—3	"	"	5	0	0	50	900
AA—4	"	"	13	4	0	60	850
AA—5	"	"	8	3	1	60	850
AA—6	"	"	3	2	0	50	900
AB—1	1	Bal	0	0	0	30	900
AB—2	"	"	3	0	0	40	850
AB—3	"	"	5	0	0	50	850
AB—4	"	"	21	0	0	50	850
AB—5	"	"	19	6	0	60	850
AB—6	"	"	15	8	3	70	800
AB—7	"	"	4	1	0	50	850
AC—1	3	Bal	0	0	0	40	850
AC—2	"	"	2	0	0	50	850
AC—3	"	"	5	0	0	60	850
AC—4	"	"	38	0	0	70	850
AC—5	"	"	40	6	0	80	850

TABLE 6

Samples	Si (wt.%)	Si Particles 3.56 × 10² (mm)² <5 μm	5—10 μm	10<—20 μm	20<—40 ±m	Seizure Load (Seizure Tester A) (kg/cm²)	Fatigue Load (Fatigue Tester B) (kg/cm²)
AC—6	"	"	31	12	4	100	800
AC—7	"	"	3	2	0	60	850
AD—1	4.7	Bal	0	0	0	50	850
AD—2	"	"	3	0	0	50	800
AD—3	"	"	5	0	0	60	800
AD—4	"	"	38	0	0	80	800
AD—5	"	"	23	6	0	90	800
AD—6	"	"	31	13	4	110	750
AD—7	"	"	3	2	0	60	800

Bearing alloys of the present invention having the compositions and nodular Si particles distribution shown in Table 6 were prepared. For comparison, Al-Si-Cu(1) alloys having a different Si content and in which the Si particles were less than 5 microns in size (Sample Nos. A21 to A24) and an Al-Si(20) alloy in which si particle formation was not controlled (Sample No. A25) were also prepared and tested and the results presented in Table 7. The data of Table 7 shows that aluminum-base bearing alloys of the present invention containing Cu, Mg, Mn or Cr alone or in various combinations, in addition to the Si, also possess outstanding seizure-resistance and fatigue-resistance properties. The alloys of the present invention also possess a seizure resistance superior to and a fatigue resistance comparable to or superior to that of the comparative alloys.

Samples	wt.%	Si Particles/3.56 x 10^{-2} (mm)^2 Size of Si particles (m) <5	5—10	10<—20	20<—40	Additional Elements (wt.%)	Seizure Load (A) kg/cm^2	Fatigue Load (B) kg/cm^2
A 1	0.5	Bal	5	0	0	Mg (0.1)	50	600
A 2	,,	,,	12	5	0		50	600
A 3	,,	,,	15	8	3	Cr (1)	50	800
A 4	,,	,,	11	6	2	Cu (0.8) Mn (0.3)	60	750
A 5	,,	,,	21	14	0	Cr (0.6)	50	800
A 6	1	,,	5	0	0		50	600
A 7	,,	,,	31	2	0	Cu (0.5)	50	600
A 8	,,	,,	19	11	5	Cu (1)	60	600
A 9	,,	,,	12	7	4	Cr (0.3)	70	750
A10	,,	,,	36	19	0	Cu (0.4) Cr (0.4)	60	750
A11	3	,,	5	0	0	Cr (0.5)	50	800
A12	,,	,,	25	4	0		60	600
A13	,,	,,	24	13	6		90	600
A14	,,	,,	18	11	7	Cu (1)	100	550
A15	,,	,,	46	34	0	Cu (0.3)	80	600
A16	4.7	,,	5	0	0	Cu (1) Mn (0.8)	60	800
A17	,,	,,	33	0	0		70	500

Samples	wt.%	Si Particles/3.56 x 10^{-2} (mm)^2 Size of Si particles (m) <5	5—10	10<—20	20<—40	Additional Elements (wt.%)	Seizure Load (A) kg/cm^2	Fatigue Load (B) kg/cm^2
A18	"	"	20	14	0	Cr (0.1)	80	600
A19	"	"	27	13	8	Mg (2)	100	500
A20	"	"	21	15	11		110	500
A21*	5	"	0	0	0	Cu (1)	50	400
A22*	11	"	0	0	0	Cu (1)	70	300
A23*	1	"	0	0	0	Cu (1)	30	600
A24*	3	"	0	0	0	Cu (1)	40	600
A25*	20	**	**	**	**		70	200

* Comparative example ** Si particles not controlled

EXAMPLE 2

Table 8 shows the composition and silicon-particle distribution of the aluminum alloy samples. The number of silicon particles in this table and the descriptions hereinbelow are per 3.56×10^{-2} mm^2.

In the present and following examples, an aluminum alloy having a predetermined composition was continuously cast so as to obtain a 15 mm-thick cast sheet. The cast sheet was subjected to peeling and subsequently was continuously cold-rolled to reduce its thickness to 6 mm. Then, intermediate annealing was carried out at 350°C. Next, a cold-rolling was carried out to form an aluminum-alloy thin sheet. The aluminum-alloy thin sheet was subjected to a high-temperature heat treatment at a temperature of from 350°C to 550°C so as to increase the size of the silicon particles.

The aluminum-alloy thin sheet was then preheated to 100°C and was pressure-welded to a steel base, which was similary preheated. Annealing for bonding was then carried out at 350°C, and a bearing was completed. When the properties of a bearing alloy per se were to be tested, pressure-welding and the steps following it were omitted.

TABLE 8

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples		Al	Si (wt.%)	Size of Si Particles (m) 2—5	5≦—<10	10≦—<20	20≦—<30	30≦—<40	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
	1	bal	0	0	0	0	0	0	15	3	0.5	0.4
BA	2	bal	3	146	0	0	0	0	15	3	0.5	0.4
	3	bal	3	231	0	0	0	0	15	3	0.5	0.4
	1	bal	3	0	0	0	0	0	15	3	0.5	0.4
BB	2	bal	3	84	20	0	0	0	15	3	0.5	0.4
	3	bal	3	53	41	0	0	0	15	3	0.5	0.4
	1	bal	0	0	0	0	0	0	15	3	0.5	0.4
	2	bal	3	42	37	6	0	0	15	3	0.5	0.4
BC	3	bal	3	63	21	12	0	0	15	3	0.5	0.4
	4	bal	3	51	24	20	0	0	15	3	0.5	0.4
	5	bal	3	36	35	29	0	0	15	3	0.5	0.4
	1	bal	0	0	0	0	0	0	15	3	0.5	0.4
BD	2	bal	3	31	19	5	3	0	15	3	0.5	0.4
	3	bal	3	27	22	14	11	0	15	3	0.5	0.4
	1	bal	3	19	24	16	6	4	15	3	0.5	0.4
BE	2	bal	3	11	18	15	14	13	15	3	0.5	0.4

The samples given in Table 8 were subjected to a seizure load test under the following conditions:

Conditon A
Tester:
Journal-Type Seizure-Testing Machine
Condition:
Opposed member (shaft): FCD70
Lubricating oil: SAE10W—30
Surface roughness of shaft: from 0.4 to 0.6 μm Rz
Lubricating oil temperature: 140°C±2.5°C
Rotation of shaft: 1,000 rpm
Diameter of shaft: 52 mm
Hardness of shaft: from 200 to 300 Hv
Load: 50 kg/cm^2 at the beginning and then increased for by 50 kg/cm^2 every 30 minutes.
Roughness of bearing: from 1 to 1.8 μm Rz
Diameter of bearing: 52 mm

The results of measurement of the seizure load are shown in Fig. 4. The abscissa of Fig. 4 indicates the number of the largest-sized silicon particles of the samples. The samples were divided into five groups of BA, BB, BC, BD, and BE in accordance with the five ranges of the largest-sized silicon particles. The following facts are apparent from Fig. 4:

A. The seizure load is influenced by the number of the largest-sized silicon particles and virtually is not influenced by the number of the smaller-sized silicon particles.

B. The seizure load increases with an increase in the number of the largest-sized silicon particles. Samples other than group BA which include larger-sized silicon particles than those of group BA exhibited a greater increase in the seizure load than did the samples of the group BA.

Considering the above-mentioned facts A and B, the present inventors propose a limitation of at least five silicon particles having a size of at least 5 microns.

EXAMPLE 3

The seizure load and fatigue strength of the samples shown in Table 9(1) were subjected to measured. The fatigue strength was measured under the following condition:

Condition B
Tester:
Alternating loading-testing machine

Condition:
Opposed member (shaft): S55C
Lubricating oil: SAE 10W—30
Surface roughness: 0.8 μm Rz
Lubricating oil temperature: 140°C ± 2.5°C
Lubricating oil pressure: 5 kg/cm^2
Rotation of shaft: 3000 rpm
Diameter of shaft: 52Φ
Hardness of shaft: Hv 500 to 600
Number of rotations of shaft: 10^7
Roughness of bearing: from 1 to 1.8 μm Rz
Diameter of bearing: 52 x 20 mm

The results of measurement are given in Table 9(2). As is apparent from Table 9(2), in accordance with the present invention, the seizure load is enhanced and the fatigue strength is not decreased due to coarse Si particles.

The number of silicon particles less than 5 microns in size was not measured and thus is not given in Table 9(1).

Since the opposed member (a shaft) is made of a carbon steel for use as a machine construction (S55C), the bearing alloy according to the present invention is effective for such an opposed member, the carbon of which member is present not as graphite.

TABLE 9 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

			Number of Si Particles (0.5 wt.%Si)						
Samples	Al	<5 μm	5—<10 μm	10—<20 μm	20—<40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
B1	bal	—	0	0	0	15	3	0.5	0.4
B2	bal	—	3	0	0	15	3	0.5	0.4
B3	bal	—	5	0	0	15	3	0.5	0.4
B4	bal	—	10	0	0	15	3	0.5	0.4
B5	bal	—	30	0	0	15	3	0.5	0.4
B6	bal	—	11	5	0	15	3	0.5	0.4
B7	bal	—	30	11	2	15	3	0.5	0.4
B8	bal	—	10	5	1	15	3	0.5	0.4
B9	bal	—	3	2	0	15	3	0.5	0.4

TABLE 9 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
B1	400	700
B2	450	700
B3	650	700
B4	750	700
B5	800	700
B6	900	700
B7	1,200	650
B8	1,100	700
B9	750	700

EXAMPLE 4

Samples having a silicon content of 1% were subjected to the same tests as in Example 3. The results, shown in Tables 10(1) and 10(2), are similar to those in Example 3.

TABLE 10 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Number of Si Particles (1 wt%Si)							
Sample	Al	<5 μm	5—<10 μm	10—<20 μm	20—<40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
B10	bal	—	0	0	0	15	3	0.5	0.4
B11	bal	—	5	0	0	15	3	0.5	0.4
B12	bal	—	11	0	0	15	3	0.5	0.4
B13	bal	—	31	0	0	15	3	0.5	0.4
B14	bal	—	11	5	0	15	3	0.5	0.4
B15	bal	—	30	11	5	15	3	0.5	0.4
B16	bal	—	30	5	0	15	3	0.5	0.4
B17	bal	—	3	2	0	15	3	0.5	0.4

TABLE 10 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue load (kg/cm²) Test Conditions B
B10	400	700
B11	650	700
B12	700	700
B13	800	700
B14	900	700
B15	1,300	650
B16	900	700
B17	750	700

EXAMPLE 5

Samples having a silicon content of 3% were subjected to the same tests as in Example 3. The results, shown in Tables 11(1) and 11(2) are similar to those in Example 3.

TABLE 11 (1)

Composition of Aluminium Alloy Samples and Distribution of Silicon Particles

		Number of Si Particles (3 wt%Si)							
Samples	Al	<5 μm	5~ <10 μm	10~ <20 μm	20~ <40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
B18	bal	—	0	0	0	15	3	0.5	0.4
B19	bal	—	5	0	0	15	3	0.4	0.4
B20	bal	—	10	0	0	15	3	0.5	0.4
B21	bal	—	41	0	0	15	3	0.5	0.4
B22	bal	—	41	10	0	15	3	0.5	0.4
B23	bal	—	65	41	10	15	3	0.5	0.4
B24	bal	—	3	2	0	15	3	0.5	0.4
B25	bal	—	65	0	0	15	3	0.5	0.4
B26	bal	—	65	5	0	15	3	0.5	0.4

TABLE 11 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
B18	400	700
B19	650	700
B20	700	700
B21	850	700
B22	1,000	650
B23	1,400	600
B24	800	700
B25	850	700
B26	900	700

EXAMPLE 6

Samples having a silicon content of 4.7% were subjected to the same tests as in Example 3. The results, shown in Tables 12(1) and 12(2), are similar to those in Example 3.

TABLE 12 (1)
Composition of Aluminium Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (4.7 wt%Si)				Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
		<5 μm	5 ∼ <10 μm	10 ∼ <20 μm	20 ∼ <40 μm				
B27	bal	—	0	0	0	15	3	0.5	0.4
B28	bal	—	5	0	0	15	3	0.5	0.4
B29	bal	—	21	0	0	15	3	0.5	0.4
B30	bal	—	63	21	0	15	3	0.5	0.4
B31	bal	—	125	63	21	15	3	0.5	0.4
B32	bal	—	31	5	0	15	3	0.5	0.4
B33	bal	—	22	11	5	15	3	0.5	0.4
B34	bal	—	3	2	0	15	3	0.5	0.4
B35	bal	—	125	5	0	15	3	0.5	0.4

TABLE 12 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
B27	450	700
B28	700	700
B29	800	700
B30	1,000	600
B31	1,400	550
B32	950	700
B33	1,300	600
B34	800	700
B35	95	650

EXAMPLE 7

The seizure load sample B12 of Example 4 and sample B19 of Example 5 was tested under Condition A. However, in this test, the surface roughness of the opposed member, i.e., the nodular-graphite cast iron shaft, was varied. For the purpose of comparison, the seizure load of the 20%Sn-1%CU-Al alloy (COMP) was measured. The results are shown in Fig. 9. It is evident that the seizure load of the present invention is excellent no matter what the surface roughness of the opposed member is. The material of the comparative example includes virtually no crystallized hard particles, and the soft Sn phases of the material have the conformability according to the general concept and provide an Al alloy having a seizure resistance. Figure 5 suggest the differences between the effects of the special the conformability the seizure resistance and the effects of the conformability according to the general concept on the seizure resistance. Since the opposed member is made of nodular graphite cast iron, it is very apparent that the material according to the present invention has a high seizure resistance against nodular graphite cast iron.

EXAMPLE 8

As is shown in Table 13, the distribution of silicon particles of the samples was made constant and the silicon content was varied. The seizure resistance of the samples was measured under Condition A, and the results of measurement are shown in Fig. 6. The fatigue strength was measured under Condition B, and the results of measurement are shown in Table 13.

TABLE 13
Composition of Aluminium Alloy Samples and Distribution of Silicon Particles

Samples	Al	Si (wt%)					Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)	Fatigue Strength (kg/cm²)
		Size of particles	<5 µm	5 ~ 10 µm	10 ~ 20 µm	20 ~ 40 µm					
		Number	—	30	11	3					
B36	bal			0.1			15	3	0.5	0.4	about 700
B37	bal			0.5			15	3	0.5	0.4	about 700
B38	bal			1			15	3	0.5	0.4	about 700
B39	bal			3			15	3	0.5	0.4	about 700
B40	bal			4.7			15	3	0.5	0.4	700
B41	bal			7			15	3	0.5	0.4	600
B42	bal			11			15	3	0.5	0.4	390

TABLE 14 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Number of Si Particles (0.5 wt%Si)												
Samples	Al	<5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
B43	bal	bal	5	0	0	25	1	—	—	—	—	2	—	—
B44	bal	bal	10	5	0	10	8	—	—	—	—	—	—	—
B45	bal	bal	30	11	2	1.5	—	—	—	—	—	—	—	—
B46	bal	bal	91	0	0	20	3	—	—	—	—	0.5	—	0.5
B47	bal	bal	53	0	0	35	—	—	—	—	—	—	—	1
B48	bal	bal	28	3	0	10	—	—	—	—	—	0.3	—	—
B49	bal	bal	3	2	0	15	—	5	—	—	—	—	—	—
B50	bal	bal	8	3	1	15	3	—	—	—	—	—	—	0.5*
B51	bal	bal	24	18	3	5	—	2	—	—	—	—	2	—
B52	bal	bal	10	0	0	30	—	—	—	—	—	1	1	1

* Manganese

TABLE 14 (1) (continued)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (1 wt%Si)				Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
		<5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm									
B53	bal	bal	5	0	0	5	—	—	—	—	—	—	—	—
B54	bal	bal	11	5	0	25	—	—	—	1	—	0.5	—	—
B55	bal	bal	30	11	5	3	—	—	—	—	—	—	—	0.5
B56	bal	bal	24	0	0	5	—	—	—	—	—	0.3	—	0.3
B57	bal	bal	5	3	0	10	—	4	—	—	—	0.5	—	—
B58	bal	bal	4	1	0	20	—	—	—	—	2	—	0.5	—
B59	bal	bal	74	0	0	15	—	—	—	—	—	—	1	—
B60	bal	bal	78	15	0	10	—	—	—	—	—	—	—	0.5
B61	bal	bal	42	11	3	5	3	—	—	—	—	—	—	—
B62	bal	bal	81	0	0	20	—	—	—	—	—	—	—	—

TABLE 14 (1) (continued)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (3 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
B63	bal	bal	10	0	0	5	2	—	2	—	—	0.8	—	0.7
B64	bal	bal	41	10	0	10	—	—	2	—	—	—	—	—
B65	bal	bal	65	41	10	15	—	—	—	—	—	—	0.5	0.1*
B66	bal	bal	5	0	0	1.5	—	—	—	—	—	0.8	—	—
B67	bal	bal	4	2	0	20	3	—	—	—	—	0.1	—	—
B68	bal	bal	25	5	0	25	—	4	—	—	—	—	—	1
B69	bal	bal	113	0	0	30	0.5	—	—	—	—	2	—	1
B70	bal	bal	83	21	0	15	3	—	—	0.5	—	0.3	—	0.1
B71	bal	bal	42	10	3	10	3	—	—	—	—	0.5	—	0.4
B72	bal	bal	37	0	0	30	—	—	—	—	—	—	—	—

* Manganese

TABLE 14 (1) (continued)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (4.7 wt%Si)				Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr
		<5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm									
B73	bal	bal	21	0	0	5	—	—	—	—	6	—	—	—
B74	bal	bal	63	21	0	10	0.5	—	—	—	—	—	—	—
B75	bal	bal	125	63	21	10	—	—	5	—	—	0.5	0.5	—
B76	bal	bal	5	0	0	10	—	—	—	—	—	—	1	—
B77	bal	bal	3	2	0	15	4	—	—	—	—	0.5	—	—
B78	bal	bal	156	0	0	15	—	—	—	2	—	—	—	—
B79	bal	bal	85	21	5	10	—	—	—	—	—	0.4	—	0.3
B80	bal	bal	38	5	0	20	—	0.5	0.5	—	—	—	0.1	0.3
B81	bal	bal	62	0	0	5	—	—	—	—	—	1	—	—
B82	bal	bal	37	3	0	10	—	—	—	—	—	—	—	—

TABLE 14 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
B43	650	650
B44	800	700
B45	1,200	700
B46	900	650
B47	900	550
B48	1,000	700
B49	800	700
B50	850	700
B51	1,250	650
B52	800	550
B53	600	700
B54	800	650
B55	1,200	650
B56	750	700
B57	900	700
B58	900	700
B59	900	700
B60	1,000	700
B61	1,300	650
B62	900	650
B63	700	700
B64	1,000	700
B65	1,400	650
B66	550	700
B67	650	700
B68	1,000	650
B69	950	650
B70	1,000	700
B71	1,400	650
B72	950	600

Test Results (continued)

Samples	Seizure Load (kg/cm^2) Test Conditions A	Fatigue Load (kg/cm^2) Test Conditions B
B73	750	700
B74	1,000	700
B75	1,400	600
B76	650	700
B77	700	700
B78	950	600
B79	1,350	650
B80	956	700
B81	900	700
B82	950	700

EXAMPLE 9

The samples given in Table 8 were subjected to the following tests:

(1) Seizure Load under Thrust Load

The seizure load of samples BC1 through BC5 was measured under the following condition:

Condition D

Tester:

Seizure tester

Condition:

Opposed member (a disc): FCD—70
Surface roughness of disc: From 1 to 1.2 μmRz
Lubricating oils: SAE10W—30 (one volume part) and kerosine (ten volume parts)
Sliding speed: 15 m/second
Method of supplying lubricating oil: a pad
Load: 10 kg/cm^2. The load was increased by 10 kg/cm^2 every ten minutes.
Roughness of bearing: from 1 to 1.8 μmRz

The results of measurement are as follows: Sample BC1, 50 kg/cm^2; Sample BC2, 70 kg/cm^2; Sample BC3, 90 kg/cm^2; Sample BC4, 110 kg/cm^2; and, Sample BC5, 170 kg/cm^2. As is apparent from these results, the seizure resistance under the thrust load increases in accordance with an increase in the number of the largest-sized (10 to 20 microns) silicon particles.

(2) Influence of Temperature of Lubricating Oil

The seizure load of sample BC2 and a comparative example (a 20%Sn-1%Cu-Al alloy) was measured under Condition A, in which the oil temperature was 80°C and 140°C. The results are shown in Fig. 7. As is apparent from Fig. 7, there was an extremely large difference in the seizure load between the material of present invention and that of the comparative example at a high temperature.

(3) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at a Lubricating Oil Temperature of 140°C.

The seizure load of sample BC2 and 20%Sn-1%Cu-Al alloy was measured under Condition A, in which the oil temperature was 140°C. The results are given in the following table.

TABLE 15
Seizure Load (kg/cm^2)

	BC2	Comparative Example
Forged Shaft	approx. 1,000	approx. 950
FCD70 Shaft	approx. 800	approx. 200

When the opposed member was a forged shaft, there was no marked difference in the seizure load between the material of the present invention and the material of the comparative example. However, there was a very marked difference when the opposed member was made of nodular graphite cast iron.

(4) Effect of Tin and Lead

The tin and lead content of BC2 was varied, and the seizure load of BC2 was measured under Condition A. The results of measurements are shown in Fig. 8. In Fig. 8, "Sn + Pb" indicates samples in which the proportion of Sn to Pb was maintained as in BC2 while the total amount of Sn and Pb was increased, "Pb"indicates samples in which the Sn amount was maintained as in BC2 while the Pb amount was increased, and "Sn" indicates samples in which the Pb amount was maintained as in BC2 while the Sn amount was increased. As is apparent from Fig. 8, tin and lead enhance the seizure resistance.

(5) Fatigue Strength

The fatigue strength of samples BA through BE was measured under Condition B. The results are showed in Fig. 9. Samples BD and BE show a relatively large decrease in the fatigue strength when the number of the largest-sized silicon particles increased.

(6) Wear Resistance

The amount of wear of sample BC2 was measured under the following condition:

Condition C

Tester:

Mixed lubrication tester

Condition:

Opposed member (a shaft): FCD70
Surface roughness of bearing: form 0.8 to 0.9 μmRz
Lubricating oil: liquid paraffin
Rotation of shaft: 100 rpm
Diameter of shaft: 40 mmφ
Hardness of shaft: from 200 to 300 Hv
Load: 25 kg

For the purpose of comparison, the amount of wear of a 20%Sn-1%Cu-Al alloy free of Si was measured under Condition C. The results of measurement are shown in Fig. 10. Wear of the comparative material increased with the passage of time, but wear of the material according to the present invention virtually ceased after one hour. The present inventors believe this difference is as follows. The comparative material, mainly the soft tin phase thereof, is uninterruptedly shaved off by the opposed member, i.e., a shaft, and the comparative material thus wears out uninterruptedly. On the other hand, in the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during an initial sliding period by coarse silicon particles which are present on the surface of the bearing. As a result, the shaft undergoes such a change that its surface may bring about an advantageous sliding condition between the shaft and bearing, such condition being virtual the fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping wearing thereof.

(7) Wear of Shaft

The roughness of the opposed member, i.e., a shaft, samples BA, BB, and BC was measured under Condition C. The results are shown in Fig. 11, in which no change in the roughness of the shaft is indicated by the ordinate 0 (μm) and roughening of the shaft surface is indicated by the plus ordinate.

As is apparent from Fig. 11, when no silicon particles 5 microns or more in size are present per 3.56×10^{-2} mm^2, i.e., zero particle of the abscissa, roughening of the shaft due to the bearing occurs.

Smoothening of the shaft is promoted when the number of the largest-sized silicon particles is great and the particle size is great. These results support the belief that coarse silicon particle have the effect of uniformly flattening the minute unevenness of the shaft surface. In addition, Sample BC containing large silicon particles of up to approximately 20 microns in size at the maximum flatten the shaft. Such flattening is outstanding and demonstrates the suitability of the coarse silicon particles.

EXAMPLE 10

The seizure load of Samples B36 through B42 is represented in Fig. 12 by the curves —0—. For the purpose of comparison bearings were produced by the same procedure as that according to the present invention. However, the aluminium alloy, which contained 15%Sn, 3%Pb, 0.5%Cu, 0.4%Cr, and varied contents of silicon, was annealed at 350°C before being pressure-welded. The seizure load of the comparative samples is represented by the curves —·— in Fig. 12.

As is apparent from Fig. 12, when the size of the silicon particles of the samples was controlled by the high-temperature heat treatment according to the present invention, the seizure resistance of the samples was enhanced.

The amount of wear of the samples according to the present invention and the comparative samples was measured under Condition G.

Condition G
Tester:
Mixed lubrication tester
Condition:
Opposed member (a shaft): FCD70
Surface Roughness of Shaft: from 0.8 to 0.9 μmRz
Lubricating oil: liquid paraffin
Rotation of shaft: 100 rpm
Diameter of shaft: 40 mmφ
Hardness of shaft: from 200 to 300 Hv
Load: 25 kg
Length of Test: 5 hours

The results of measurement are shown in Fig. 13. As is apparent from Fig. 13, the high-temperature heat treatment according to the present invention attains control of the size of the silicon particles and considerably enhances the wear resistance of the tin-containing aluminum alloy.

EXAMPLE 11

An aluminum alloy containing 3%Si, 15%Sn, 3%Pb, 0.5%Cu and 0.4%Cr was subjected to annealing at the various temperatures given below before being pressure-welded, and the microstructures in a horizontal plane are shown in the figures listed below.

270°C (comparative example, a low-temperature heat treatment):	Fig. 14
400°C	Fig. 15
480°C (slow cooling was carried out after heating)	Fig. 16
530°C	Fig. 17

In Fig. 14, which shows the structure of the comparative example, most of the silicon particles are less than 5 microns in size, and several of the silicon particles 5 microns or more in size have an acicular flat form elongated in the rolling direction.

Fig. 15 is an example in which the size of the silicon particles in controlled, thereby obtaining a size of from 5 to 10 microns. From a comparison of Fig. 14 and Fig. 15, it can be seen that in Fig. 15 the number of fine silicon particles less than 5 microns in size is decreased and that coarse and nodular silicon particles 5 microns or more in size are formed. Therefore, it can be assumed that fine silicon particles incorporate each other and are changed to coarse particles due to a high-temperature heat treatment.

In Fig. 16, the size of the silicon particles is controlled to from more than 10 microns to 20 microns or less, and in Fig. 17 the size of the silicon particles is controlled to form more than 20 microns to 30 microns or less. The precipitates, which are long as compared with the nodular particles, are Sn + Pb alloy particles. As is apparent from a comparison of Fig. 15 and Fig. 16, the Sn + Pb alloy particles coarsen due to the high-temperature heat treatment. The Sn + Pb alloy particles become irregularly shaped and the silicon particles become regularly shaped, such as polygonal shaped, due to the high-temperature heat treatment. Thus, the behaviour of the Sn + Pb alloy particles and the behaviour of the silicon particles during the high-temperature heat treatment are clearly different.

In this regard, since Sn + Pb alloy particles have a low melting point, it can be foreseen to a certain extent, based on general knowledge of the tin (lead)-containing metallic materials, that the shape of Sn + Pb alloy particles changed due to melting and softening. However, there is no technically reasonable explanation for the incorporation of silicon particles and incidentally occurring nodularization.

EXAMPLE 12 (Al-Si-Pb base alloy)

In Table 16, the composition of the silicon-particle distribution of aluminum alloy samples is given.

TABLE 16
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples		3 wt% size of Si Particles (μm) 2≦~ <5	5≦~ <10	10≦~ <20	20≦~ <30	30≦~ <40	Pb (wt%)	Cu (wt%)	Cr (wt%)
CA	1	155	0	0	0	0	4	0.5	0.4
	2	293	0	0	0	0	4	0.5	0.4
	3	436	0	0	0	0	4	0.5	0.4
CB	1	—	5	0	0	0	4	0.5	0.4
	2	—	32	0	0	0	4	0.5	0.4
	3	—	93	0	0	0	4	0.5	0.4
CC	1	—	37	6	0	0	4	0.5	0.4
	2	—	49	21	0	0	4	0.5	0.4
	3	—	41	33	0	0	4	0.5	0.4
CD	1	—	53	21	6	0	4	0.5	0.4
	2	—	34	14	11	0	4	0.5	0.4
	3	—	44	18	15	0	4	0.5	0.4
CE	1		32	18	4	1	4	0.5	0.4
	2		45	13	7	5	4	0.5	0.4

The seizure load of the samples given in Table 16 was measured under Condition A. The results of measurement are shown in Fig. 18, in which the abscissa indicates the number of the largest-sized silicon particles. The following facts are apparent from Fig. 18.

The seizure load was influenced by largest-sized silicon particles. That is, the seizure load increased in the following ascending order of BA, BB, BC, BD, and BE. The seizure load of the samples other than CA increased in accordance with the number of the largest-sized silicon particles. The seizure load of Sample CA, which is outside the present invention, was 500 kg/cm² at the highest. The seizure load according to the present invention is twice as high as that of Sample CA.

EXAMPLE 13

The seizure load and fatigue strength of the samples given in Table 17 (1) were measured under Condition B. The results of measurement are given in Table 17 (2). As is apparent from Table 17 (2), the seizure load is enhanced according to the present invention, and the fatigue strength is not impaired due to coarse silicon particles.

Incidentally, the number of silicon particles less than 5 microns in size was not measured. The opposed member, i.e., a shaft, used for measuring the seizure load was made of carbon steel for machine and contruction use (S55C). The bearing alloy according to the present invention is useful even when the carbon of the opposed member is not present is graphite.

TABLE 17 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Number of Si Particles (0.5 wt%Si)						
Samples	Al	<5 μm	5m <10 μm	10 m <20 μm	20 m <40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
C1	bal	—	0	0	0	4	0.5	0.4
C2	bal	—	3	0	0	4	0.5	0.4
C3	bal	—	5	0	0	4	0.5	0.4
C4	bal	—	11	0	0	4	0.5	0.4
C5	bal	—	29	0	0	4	0.5	0.4
C6	bal	—	13	5	0	4	0.5	0.4
C7	bal	—		10	2	4	0.5	0.4
C8	bal	—	3	2	0	4	0.5	0.4

TABLE 17 (2)
Test Results

Samples	Seizure Load (kg/cm^2) Test Conditions A	Fatigue Load (kg/cm^2) Test Conditions B
C1	300	800
C2	350	750
C3	500	750
C4	550	750
C5	600	750
C6	700	750
C7	900	700
C8	500	750

EXAMPLE 14

Samples having a silicon content of 1% were subjected to the same experiments as those in Example 13, and the results given in Tables 18 (1) and (2) were obtained. These results are the same as those in Example 13.

TABLE 18 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (1 wt%Si) <5 θm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb (wt%)	Cu (wt%)	(wt%)
C9	bal	—	0	0	0	4	0.5	0.4
C10	bal	—	5	0	0	4	0.5	0.4
C11	bal	—	10	0	0	4	0.5	0.4
C12	bal	—	30	0	0	4	0.5	0.4
C13	bal	—	11	5	0	4	0.5	0.4
C14	bal	—	31	11	5	4	0.5	0.4
C15	bal	—	31	4	0	4	0.5	0.4
C16	bal	—	3	2	0	4	0.5	0.4

TABLE 18 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
C9	350	800
C10	500	750
C11	550	750
C12	600	750
C13	700	750
C14	1,000	700
C15	700	750
C16	500	750

EXAMPLE 15

Samples having a silicon content of 3% were subjected to the same experiments as those in Example 13, and the results given in Tables 19 (1) and (2) were obtained. The results are virtually the same as those in Example 13.

TABLE 19 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (3 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
C17	bal	—	0	0	0	4	0.5	0.4
C18	bal	—	5	0	0	4	0.5	0.4
C19	bal	—	11	0	0	4	0.5	0.4
C20	bal	—	40	0	0	4	0.5	0.4
C21	bal	—	41	11	0	4	0.5	0.4
C22	bal	—	64	40	9	4	0.5	0.4
C23	bal	—	65	5	0	4	0.5	0.4
C24	bal	—	3	2	0	4	0.5	0.4

TABLE 19 (2)
Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
C17	400	750
C18	550	700
C19	600	700
C20	650	700
C21	850	650
C22	1,100	600
C23	800	650
C24	550	700

EXAMPLE 16

Samples having a silicon content of 4.7% were subjected to the same experiments as those in Example 13, and the results given in Table 20 (1) and (2) were obtained. The results are virtually the same as those in Example 13.

TABLE 20 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (4.7 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
C25	bal	—	0	0	0	4	0.5	0.4
C26	bal	—	5	0	0	4	0.5	0.4
C27	bal	—	22	0	0	4	0.5	0.4
C28	bal	—	34	2	0	4	0.5	0.4
C29	bal	—	65	20	0	4	0.5	0.4
C30	bal	—	128	33	2	4	0.5	0.4
C31	bal	—	125	5	0	4	0.5	0.4
C32	bal	—	3	2	0	4	0.5	0.4

TABLE 20 (2)
Test Results

Samples	Seizure Load (kg)cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
C25	450	700
C26	600	650
C27	650	650
C28	750	600
C29	850	550
C30	1,100	500
C31	850	600
C32	600	650

EXAMPLE 17

The seizure load of sample CC3 of Example 13 was measured under Condition A except that the surface roughness of the nodular graphite cast iron shaft, i.e., the opposed member, was varied. The seizure load of a 4%Sn-1%Cu-Al alloy was measured for the purpose of comparison. The results of measurement are given in Table 21.

TABLE 21
Seizure Load (kg/cm²)

Samples	Surface Roughness (μmz) 0.2	0.5	1	3
CC3	1,000	700	450	310
Comparative Samples	300	—	110	60

It is evident that the seizure load of the present invention is excellent irregardless of the surface roughness of the opposed member. The material of the comparative example includes virtually no crystallized hard particles. In addition, the soft Sn phases of such material have the conformability according to the general concept and provide an Al alloy with seizure resistance. Therefore, Table 21 gives a hint as to the difference between the effects of the special conformability upon the seizure resistance and those of the conformability according to the general concept. Since the opposed member is made of nodular graphite cast iron, it should be very apparent that the material according to the present invention has a high seizure resistance against nodular graphite cast iron.

EXAMPLE 18

As Table 13 shown, the distribution of silicon particles of the samples was made constant, and the silicon content was varied. The seizure resistance of the samples was measured under Condition A, and the results are shown in Fig. 19. The fatigue strength was measured under Condition B, and the results are shown in Table 22.

TABLE 22
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Si (wt%)								
Samples	Al	Particles Size Number	<5 ~ μm ba l	<5 ~ 10 μm 30 ~ 35	<10 ~ 20 μm 8 ~ 11	<20 ~ 40 μm 2 ~ 4	Pb (wt%)	Cu (wt%)	Cr (wt%)	Fatigue Strength (Kg/cm²)
C33	bal			0.5			4	0.5	0.4	800
C34	bal			1			4	0.5	0.4	750
C35	bal			3			4	0.5	0.4	750
C36	bal			4.7			4	0.5	0.4	755
C37	bal			7			4	0.5	0.4	670
C38	bal			11			4	0.5	0.4	530

As is apparent from Fig. 19, the seizure load becomes maximum when the silicon content is approximately 3%. As was mentioned hereinabove, the seizure load is controlled by the number and size of the largest-sized silicon particles as long as the silicon content lies within the range of the present invention. However, in the present example, in which the number of silicon particles 5 microns in size was kept constant, the silicon content exerted an influence on the seizure load. Fine silicon particles less than 5 microns in size seem to exert such an influence.

As is apparent from Table 22, the fatigue strength the decreases at a silicon content of more than 5%. This seems to be due to the above-mentioned fine particles.

EXAMPLE 19

The same experiments as those in Example 13, 14, 15, and 16 were carried out while varying the kinds of lead and the like and copper and the like. The results are given in Tables 23 (1) and 23 (2). As is apparent from these tables, a satisfactory seizure load and fatigue strength can be obtained when various optional elements are used.

TABLE 23 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (0.5 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
C39	bal	—	5	0	0	4	—	—	—	—	0.5	—	—
C40	bal	—	11	0	0	—	4	—	—	—	—	—	1
C41	bal	—	53	0	0	—	—	—	—	8	—	—	—
C42	bal	—	92	0	0	5	—	—	—	—	—	—	0.5*
C43	bal	—	10	5	0	—	5	—	—	—	—	—	—
C44	bal	—	30	12	1	4	—	—	—	—	0.5	—	0.4

*Manganese

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (1 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
C45	bal	—	5	0	0	—	—	—	0.5	—	—	—	0.5*
C46	bal	—	10	0	0	1	—	—	—	—	0.1	—	0.1
C47	bal	—	54	0	0	0.5	—	—	—	—	—	—	—
C48	bal	—	93	0	0	3	—	0.5	—	—	—	—	0.8
C49	bal	—	12	5	0	—	—	3	—	—	—	1	—
C50	bal	—	31	11	2	2	—	—	—	—	0.8	—	0.2
C51	bal	—	54	12	5	4	—	—	—	—	0.5	—	0.5*

*Manganese

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (3 wt%Si)				Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
		<5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm								
C52	bal	—	5	0	0	3	—	—	1	—	0.2	0.3	—
C53	bal	—	32	0	0	—	—	—	—	2	—	—	—
C54	bal	—	94	0	0	6	—	—	—	—	—	0.5	0.5*
C55	bal	—	11	5	0	3	—	—	—	—	2	—	—
C56	bal	—	32	11	3	4	—	—	—	—	—	—	0.3
C57	bal	—	94	20	0	—	—	2	—	—	0.3	—	0.2
C58	bal	—	4	1	0	—	5	—	—	—	1	0.5	0.5

*Manganese

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (4.7 wt%Si) <5 μm	5 ~ <10 μm	10 ~ <20 μm	20 ~ <40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
C59	bal	—	5	0	0	3	—	—	—	—	0.4	—	0.6
C60	bal	—	31	0	0	1	—	—	—	—	0.2	—	0.1*
C61	bal	—	95	0	0	2	—	1	—	—	0.1	—	—
C62	bal	—	25	5	0	3	—	—	—	—	1	—	—
C63	bal	—	36	10	5	—	—	—	3	—	1.5	—	1.0
C64	bal	—	94	5	0	—	3	—	—	—	—	—	—

*Manganese

TABLE 23 (2)

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
C39	500	700
C40	550	800
C41	600	650
C42	650	800
C43	700	650
C44	900	700
C45	500	800
C46	550	750
C47	600	700
C48	650	750
C49	700	700
C50	950	700
C51	1,050	700
C52	600	700
C53	650	650
C54	700	700
C55	750	600
C56	1,050	600
C57	950	600
C58	600	750
C59	650	700
C60	700	600
C61	800	550
C62	900	550
C63	1,100	550
C64	950	500

EXAMPLE 20

The following experiments were carried out using a sample given in Table 16.

(1) Influence of Temperature of Lubricating Oil

The seizure load of sample CC3 and a 4%Sn-1%Cu-Al alloy as the comparative example was measured under Condition A, in which the oil temperature was 80°C and 140°C. The results are given in Table 24.

TABLE 24
(Seizure Load in kg/cm^2)

Sample	Oil Temperature (°C) 80	140
CC3	1,300	1,000
Comparative Example	800	200

As is apparent from Table 24 there is an extremely large difference in the seizure load between the material of present invention and that of the comparative example at a high temperature.

(2) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at a Lubricating Oil Temperature of 140°C.

The seizure load of sample CC3 and 4%Sn-1%Cu-Al alloy was measured under Condition A (oil temperature —140°C), in which the results are given in the following table.

TABLE 25
Seizure Load (kg/cm^2)

	BC2	Comparative Example
Forged Shaft	approx. 1,100	approx. 990
FCD70 Shaft	approx. 1,010	approx. 260

(3) Wear Resistance

The amount of wear of sample CC3 and the 4%Sn-1%Cu-Al alloy was measured under Condition C. The results are shown in Fig. 20. Wear of the comparative material increased with the passage of time, but wear of the material according to the present invention virtually caused after one hour. The present inventors believe this difference as is follows.

In the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during the initial sliding period by coarse silicon particles which are present on the surface of a bearing. As a result, the shaft undergoes such a change that its surface may bring about an advantageous sliding condition between the shaft and bearing, such a condition being virtual fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping wearing thereof.

EXAMPLE 21 COMPARATIVE EXAMPLE)

Bearings were produced by the same procedure as that according to the present invention except that the aluminum alloy containing 3%Sn, 3%Pb, 0.5%Cu, and 4%Cr was annealed at 350°C before it was pressure-welded. The seizure load was measured under Condition A, and the results of measurement are shown in Fig. 21. When the seizure loads shown in Fig. 19 and 21 are compared, with the silicon content of both being identical, that, is, less than 5%, it is apparent that the seizure load of the present invention is considerably higher than that of the comparative sample.

The amount of wear of the comparative sample mentioned above and Samples C33 through 38 (Example 17) of present invention was measured under Condition C. The results of measurement are

shown in Fig. 22. As is apparent from this drawing, when the size of the silicon particles is controlled by the high-temperature heat treatment according to the present invention, the wear resistance of the lead-containing aluminum alloy is considerably enhanced.

EXAMPLE 22

An aluminum alloy containing 3%Si, 4%Pb, 0.5%Cu, and 0.4%Cr was subjected to annealing at the various temperatures given below before being pressure-welded, and the microstructures in a horizontal plane were observed.

200°C (comparative example, a low-temperature heat treatment)
400°C
480°C
530°C (slow cooling was carried out heating)

In the structure of the comparative example, most of the silicon particles less than 5 microns in size, and several silicon particles 5 microns or more in size had an acicular flat form elongated in the rolling direction.

The size of the silicon particles can be controlled, for example, by carrying out a heat treatment at 400°C. Thereby, silicon particles from 5 to 10 microns in size can be obtained. From a comparison of the comparative example and the heat treatment at 400°C, it can be seen that the number of fine silicon particles less than 5 microns in size is decreased and that coarse and nodular silicon particles of 5 microns or more in size are formed due to a heat treatment carried out at 400°C. Therefore, it can be assumed that fine silicon particles incorporate each other and are changed to coarse particles due to a high-temperature treatment.

Due to heat treatments carried out at 400°C and 480°C, the size of the silicon particles is controlled to from more than 10 microns to 20 microns or less and from more than 20 microns to 30 microns or less, respectively. Detected long crystals other than nodular silicon particles are Pb alloy particles. From a comparison of a heat treatment carried out at 48°C and a heat treatment carried out at 530°C, it was revealed that the Pb alloy particles coarsen due to a higher-temperature heat treatment. The Pb alloy particles assume an irregular shape and the silicon particles assume a regular shape, such as a polygonal shape, due to a high-temperature heat treatment. Thus, the behaviour of the Pb alloy particles and the behavior of the silicon particles during a high-temperature heat treatment are clearly different.

EXAMPLE 23

Table 26 shows the aluminum-alloy composition and silicon particle distribution of the samples. In this table and in the descriptions below, the number of silicon particles is per 3.56×10^{-2} mm^2 except when otherwise specified. The number silicon particles from 2 to 5 microns in size was not measured in Samples DB1 through DE1.

TABLE 26
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	8 wt% size of Si Particles (μm) 2 ~ 5	5 ~ 10	10< ~ 17	17< ~ 30	30< ~ 40	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
1	bal	185	0	0	0	0	15	3	0.5	0.4
DA 2	bal	368	0	0	0	0	15	3	0.5	0.4
3	bal	623	0	0	0	0	15	3	0.5	0.4
1	bal	—	5	0	0	0	15	3	0.5	0.4
DB 2	bal	—	46	0	0	0	15	3	0.5	0.4
3	bal	—	104	0	0	0	15	3	0.5	0.4
1	bal	—	59	6	0	0	15	3	0.5	0.4
DC 2	bal	—	48	21	0	0	15	3	0.5	0.4
3	bal	—	39	35	0	0	15	3	0.5	0.4
1	bal	—	37	13	5	0	15	3	0.5	0.4
DD 2	bal	—	31	22	16	0	15	3	0.5	0.4
3	bal	—	28	23	22	0	15	3	0.5	0.4
DE 1	bal	—	27	17	8	6	15	3	0.5	0.4

The seizure load of the samples of Table 26 was measured under the following condition in which the sliding condition was made severe by the use of a low-viscosity bibricating oil.

Condition A′
Tester:
Journal-Type Seizure-Testing Machine Conditions:
Opposed member (a shaft): FCD70
Lubricating oil: SAE5W—30
Surface roughness of shaft: from 0.4 to 0.6 μm Rz
Lubricating oil temperature: 160 $\pm$2.5°C
Rotation of shaft: 1,000 rpm
Diameter of shaft: 52 mm
Hardness of shaft: from 200 to 300 Hv
Load: 50 kg/cm^2 at the beginning and then increased by 50kg/cm^2 every 30 min.
Roughness of bearing: from 1 to 1.8 μm Rz
Diameter of bearing: 52 mm

The results of measurement of the seizure load are shown in Fig. 24. The abscissa of Fig. 24 indicates the number of largest-sized silicon particles of the samples. The samples were divided into five groups of DA, DB, DC, DD, and DE in accordance with the five ranges of the largest-sized silicon particles. The following fact is apparent from Fig. 24. The seizure load is influenced by the number of the largest-sizes silicon particles and is virtually not influenced by the number of the smaller-sized silicon particles.

The present inventors propose a limitation of at least five silicon particles at least 5 microns in size.

EXAMPLE 24

The seizure load under Condition A, the fatigue strength under Condition B′, and the amount of wear under Condition G of the samples shown in Table 27(1) were measured.

Condition B′
Tester:
Alternating Load-Testing Machine
Conditions:
Lubricating oil: SAE10W 30
Surface roughness: 0.8 μm Rz
Lubricating oil temperature: 140 $\pm$ 2.5°C
Lubricating oil pressure: 5 kg/cm^2
Rotation of shaft: 3,000 rpm
Diameter of shaft: 52φ
Hardness of shaft: from 500 to 600 Hv
Number of rotations of shaft: 10^7
Roughness of bearing: from 1 to 1.8 μm Rz
Diameter of bearing: 52 × 20 mm

The results of measurement are given in Table 27(2).

As is apparent from this table, in accordance with the present invention, the seizure resistance and wear resistance are enhanced and the fatigue resistance is not decreased appreciably due to coarse Si particles.

The wear amount was measured under Condition G.
Tester:
Mixed lubrication tester
Condition:
Opposed member (a shaft): FCD70
Surface Roughness of Shaft: from 0.8 to 0.9 μm Rz
Lubricating oil: liquid paraffin
Rotation of shaft: 100 rpm
Diameter of shaft: 40 mm
Hardness of shaft: from 200 to 300 Hv
Load: 25 kg
Length of Test: 5 hours

TABLE 27 (1)
Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Composition Samples	Al	Number of Si Particles (5 wt%Si)					Sn	Pb	Cu	Cr
		<5 μm	5< ~ 10 μm	10< ~ 17 μm	17< ~ 25 μm	25< ~ 40 μm				
D1 (Comparative Samples)	bal	—	0	0	0	0	15	3	0.5	0.4
D2 (Comparative Samples)	bal	—	2	0	0	0	15	3	0.5	0.4
D3	bal	—	5	0	0	0	15	3	0.5	0.4
D4	bal	—	56	0	0	0	15	3	0.5	0.4
D5	bal	—	48	23	0	0	15	3	0.5	0.4
D6	bal	—	31	17	5	0	15	3	0.5	0.4
D7	bal	—	26	15	6	2	15	3	0.5	0.4

TABLE 27 (2)
Test Results

Performance Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B	Amount of Wear (mm³) Test Conditions G
D1 (Comparative Samples)	450	800	5
D2 (Comparative Samples)	500	800	4
D3	700	800	3
D4	750	800	2.5
D5	800	800	2
D6	900	800	2
D7	950	750	2

EXAMPLE 25

Samples having a silicon content of 8% were subjected to the same experiments as those in Example 24, and the results given in Tables 28(1) and 28(2) were obtained. The results were virtually the same as those in Example 24.

TABLE 28 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (8 wt%Si) <5 μm	5 ~ 10 μm	10< ~ 17 μm	17< ~ 25 μm	25< ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
D8 (comparative Samples)	bal	—	0	0	0	0	15	3	0.5	0.4
D9 (Comparative Samples)	bal	—	3	0	0	0	15	3	0.5	0.4
D10	bal	—	5	0	0	0	15	3	0.5	0.4
D11	bal	—	61	0	0	0	15	3	0.5	0.4
D12	bal	—	81	33	0	0	15	3	0.5	0.4
D13	bal	—	53	25	6	0	15	3	0.5	0.4
D14	bal	—	33	18	7	4	15	3	0.5	0.4

TABLE 28 (2)

Test Results

Performance / Samples	Seizure Load (kg-cm^2) Test Conditions A'	Fatigue Load (kg/cm^2) Test Conditions B	Amount of Wear (mm^3) Test Conditions G
D8 (Comparative Samples)	450	700	5
D9 (Comparative Samples)	550	700	4
D10	700	700	3.5
D11	800	650	3
D12	850	600	2.6
D13	900	600	2.5
D14	950	550	2.2

EXAMPLE 26

Samples having a silicon content of 11% were subjected to the same experiments as those in Example 24. The results are given in Tables 29 (1) and 29 (2). The results were virtually the same as those in Example 24.

TABLE 29 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Number of Si Particles (11 wt%Si)								
Samples	Al	<5 μm	5 ~ 10 μm	10< ~ 17 μm	17< ~ 25 μm	25< ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
D15 (Comparative Samples)	bal	—	0	0	0	0	15	3	0.5	0.4
D16 (Comparative Samples)	bal	—	3	0	0	0	15	3	0.5	0.4
D17	bal	—	5	0	0		15	3	0.5	0.4
D18	bal	—	94	0	0	0	15	3	0.5	0.4
D19	bal	—	71	38	0	0	15	3	0.5	0.4
D20	bal	—	88	22	8	0	15	3	0.5	0.4
D21	bal	—	26	18	11	8	15	3	0.5	0.4

TABLE 29 (2)

Test Results

Performance / Samples	Seizure Load (kg-cm^2) Test Conditions A′	Fatigue Load (kg/cm^2) Test Conditions B	Amount of Wear (mm^3) Test Conditions G
D15 (Comparative Samples)	500	600	7
D16 (Comparative Samples)	550	600	6
D17	600	600	5
D18	650	550	4
D19	700	500	3
D20	750	450	2.8
D21	800	400	2.5

EXAMPLE 27

As is ahown in Table 30, the distribution of silicon particles of the samples was made constant and the silicon content was varied. The seizure resistance of the samples was measured under Condition A′, and the results are shown in Fig. 25. The fatigue strength was measured under Condition B′, and the results are shown in Fig. 26.

TABLE 30

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Si (wt%)									
Samples	Al	Size of Particles	<5 μm	5 ~ 10 μm	10< ~ 17 μm	17< ~ 25 μm	25< ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
		Number	—	31 ~ 35	8 ~ 11	4 ~ 6	1 ~ 3				
D22	bal			1				15	3	0.5	0.4
D23	bal			3				15	3	0.5	0.4
D24	bal			5				15	3	0.5	0.4
D25	bal			7				15	3	0.5	0.4
D26	bal			9				15	3	0.5	0.4
D27	bal			11				15	3	0.5	0.4
D28	bal			13				15	3	0.5	0.4
D29	bal			15				15	3	0.5	0.4

As is apparent from Fig. 25, the seizure load reached a maximum value when the silicon content was approximately 6%. As was mentioned above, the seizure resistance is attained according to the present invention by the fact that the silicon particles realize a special conformability and support a shaft. Since in the present example the distribution of silicon particles 5 microns or more in size is maintained constant, the contribution of the special conformability to the seizure resistance is believed to be constant notwithstanding the silicon content. However, the seizure load. i.e., the seizure resistance, is the highest at a silicon content of approximately 6% because the effects of fine silicon particles less than 5 microns in size are most outstanding and strongly support the coarse silicon particles in the aluminum matrix. When the silicon content is more than approximately 6%, the reliability of the aluminum matrix, especially the reliability of the dynamic behavior of the aluminum matrix, is poor and the fatigue phenomenon is prominent, with the result that the strength of the aluminum matrix is lowered and thus the seizure resistance of the entire alloy is lowered.

As is apparent from Fig. 26, when the silicon content exceeds 5% the fatigue resistance is low because of the presence of the above-described fine particles.

EXAMPLE 28

The seizure load, fatigue strength, and amount of wear of samples in which different kinds of lead and the like, copper and the like, and chromium were varied were measured. The results are given in Tables 31 (1) through 33 (2). As is apparent from these tables, the control of coarse silicon particles according to the present invention makes it possible to obtain aluminum alloys containing various kinds of additional elements and having excellent bearing characteristics.

TABLE 31 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

wt%

Samples	Al	Si Particles (5 wt%Si) <5 μm	5~ 10 μm	10<~ 17 μm	17<~ 25 μm	25<~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
D30	bal	—	5	0	0	0	15	—	—	—	—	—	0.5	—	0.4
D31	bal	—	25	1	4	1	10	—	—	—	—	—	—	—	—
D32	bal	—	83	0	0	0	1.5	3	—	—	—	—	—	—	—
D33	bal	—	36	23	5	0	20	—	—	—	—	—	—	—	1
D34	bal	—	18	5	0	0	15	—	—	—	—	—	0.5	—	0.4
D35	bal	—	31	28	11	4	10	5	—	—	—	—	0.8	—	—
D36	bal	—	44	16	1	0	25	—	—	2	—	—	1	—	—
D37	bal	—	103	0	0	0	5	—	—	—	—	—	0.1	—	0.1*
D38	bal	—	62	19	3	0	10	—	—	—	0.5	—	—	—	0.8
D39	bal	—	48	15	0	0	35	—	—	—	—	—	2	—	—
D40	bal	—	5	0	0	0	15	—	—	—	—	—	0.5	—	0.4*
D41	bal	—	21	6	2	0	1.5	—	5	—	—	—	—	—	—

* Manganese

TABLE 31 (2)

Samples	Test Results Seizure Load (kg-cm^2) Test Conditions A′	Fatigue Load (kg/cm^2) Test Conditions B	Amount of Wear (mm^3) Test Conditions G
D30	700	800	5
D31	850	550	2
D32	750	600	4
D33	850	750	2
D34	750	800	3
D35	900	550	2
D36	850	600	3
D37	750	750	4
D38	850	750	3
D39	800	600	4
D40	700	700	5
D41	850	550	4

TABLE 32 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

wt%

Samples	Al	Si Particles (8 wt%Si) <5 μm	5~ 10 μm	10<~ 17 μm	17<~ 25 μm	25<~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
D42	bal	—	63	0	0	0	30	2	—	1	—	—	1	—	—
D43	bal	—	20	6	0	0	15	3	—	—	—	—	0.5	—	0.4
D44	bal	—	121	0	0	0	20	—	—	—	—	—	—	0.8	—
D45	bal	—	42	13	0	0	10	—	—	—	—	—	—	2	1*
D46	bal	—	36	19	8	2	5	—	—	—	—	—	—	—	0.3
D47	bal	—	29	21	11	0	10	1	—	—	—	—	—	—	0.5
D48	bal	—	13	4	1	0	10	—	—	1	1	—	0.1	—	—
D49	bal	—	48	25	11	6	35	—	5	—	—	—	0.5	0.5	—
D50	bal	—	5	0	0	0	15	3	—	—	—	—	0.5	—	0.4*
D51	bal	—	42	19	6	0	1.5	—	—	—	—	—	—	—	—
D52	bal	—	26	15	4	1	10	—	—	—	—	—	—	—	—
D53	bal	—	85	21	0	0	20	—	2	—	—	—	—	—	—

* Manganese

TABLE 32 (2)

Test Results

Samples	Seizure Load (kg-cm^2) Test Conditions A′	Fatigue Load (kg/cm^2) Test Conditions B	Amount of Wear (mm^3) Test Conditions G
D42	750	550	6
D43	800	600	5
D44	800	500	6
D45	800	700	5
D46	900	650	2
D47	900	650	2.5
D48	800	550	3
D49	800	500	3
D50	650	600	7
D51	750	350	5
D52	800	350	5
D53	700	350	6

TABLE 33(1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

wt%

		Si (11 wt%Si)													
Samples	Al	<5 µm	5 ~ 10 µm	10< ~ 17 µm	17< ~ 25 µm	25< ~ 40 µm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
D54	bal	—	23	6	0	0	5	—	—	—	—	5	1	—	—
D55	bal	—	41	33	21	0	15	5	—	—	—	—	—	—	0.5
D56	bal	—	36	17	8	4	35	—	—	2	—	—	2	—	1
D57	bal	—	81	0	0	0	20	—	—	—	—	—	0.8	—	—
D58	bal	—	53	20	0	0	25	—	—	—	—	—	0.5	—	0.4*
D59	bal	—	32	5	0	0	10	—	—	0.5	0.5	—	—	—	—

* Manganese

TABLE 33 (2)

Test Results

Samples	Seizure Load ($kg\text{-}cm^2$) Test Conditions A′	Fatigue Load (kg/cm^2) Test Conditions B	Amount of Wear (mm^3) Test Conditions G
D54	700	350	6
D55	800	450	4
D56	800	450	2.5
D57	700	350	7
D58	750	400	6
D59	650	350	6

EXAMPLE 29

The samples given in Table 26 were subjected to the following experiments:

(1) Wear Test (Condition G)

The results are shown in Fig. 27. As is apparent from Fig. 27, the wear resistance of a Sn-containing aluminum alloy is first determined by the largest-sized silicon particles, i.e., one of the groups DA through DE, and second by the number of the largest-sized silicon particles.

(2) Influence of Lubricating Oil Temperature

The seizure load of sample DC2 was measured under Condition A′, in which the lubricating oil temperature was 80°C and 140°C. For the purpose of comparison, the seizure load of a 20% Sn-1% Cu-Al alloy was also measured under Condition A′. The results are given in Table 34.

TABLE 34

Seizure Load (kg/cm^2)

Samples	Oil Temperature (°C)	
	80	160
DC2	1,00	860
Comparative Example	900	260

As is apparent from this table, there is a great difference in the seizure load between the material of the present invention and the material of the comparative example at a high temperature.

(3) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at an Oil Temperature of 140°C.

The seizure load of sample DC2 and a 20% Sn-1% Cu-Al alloy as a comparative example was measured under Condition A, in which the oil temperature was 140°C. The results are given in the following table.

TABLE 35

Seizure Load (kg/cm^{2})

	DC2	Comparative Example
Forged Shaft	approx. 1,000	approx. 1,000
FCD70	approx. 850	approx. 250

There was no difference in the seizure load between the material of the present invention and the material of the comparative example when the opposed member was forged, but the difference was extremely great when the opposed member was nodular cast iron (DCI).

(4) Dispersion of Values of Seizure Load

Three samples of DC2 and three comparative samples having the composition 20%Sn,-1%Cu-Al and three comparative samples having the composition 8%Si-1% Cu-Al were prepared. In the comparative samples, the size of the silicon particles was less than 5 microns. The seizure load of the samples was measured under Condition A′. The results are shown in Fig. 28. As is apparent from Fig. 28, the seizure load was high and the dispersion of values was low in the material of the present invention (DC2).

(5) Wear Resistance

The amount of wear of sample DC2 was the measured under Condition C.

For the purpose of comparison, the amount of wear of a 20%Sn-1%Cu-Al alloy-COMPD(1) free of Si and a 8%Si-1%Cu-Al alloy-COMPD(2)- was measure under Condition C. The results of measurement are shown in Fig. 29. Wear of the comparative materials increased with the passage of time, but wear of the material according to the present invention virtually ceased after two hours. The present inventors believe this difference is as follows. The comparative materials (1) and (2), mainly the soft tin phases thereof, are uninterruptedly shaved off by the opposed member, i.e., a shaft, and the comparative materials thus wear out uninterruptedly. In the comparative material (2), the silicon particles less than 5 microns in size did not appreciably contribute to the wear resistance, and the aluminum matrix was brittle due to a small amount of soft metal. On the other hand, in the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during an initial sliding period by coarse silicon particles which are present on the surface of a bearing. As a result, the shaft undergoes such a change that its surface may bring about an advantageous sliding condition between the shaft and bearing, such condition being virtual fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping the wearing thereof.

EXAMPLE 30

Aluminum alloys of comparative samples containing 15%Sn, 3%Pb, 0.5%Cu, 0.4Cr, and varied contents of silicon were subjected to a bearing production step but were annealed at 350°C before being pressure-welded. The seizure load of the comparative samples was measured under Condition A′. The results are shown in Fig. 30. As is apparent from a comparison of Fig. 30 and Fig. 25, when the size of the silicon particles of the samples was controlled by a high-temperature heat treatment according to the present invention, the seizure resistance of the samples was enhanced.

The amount of wear of samples D29 through D36 (Table 31) according to the present invention and the comparative samples was measured under condition G.

The results are shown in Fig. 31. As is apparent from this drawing, the high-temperature heat treatment according to the present invention attains control of the size of silicon particles and considerably enhances the wear resistance of the tin-containing aluminum alloy (D29 through 36).

An aluminum alloy containing 8-Si, 15%Sn, 3%Pb, 0.5%Cu, and 0.4%Cr was subjected to annealing at the temperatures given below before being pressure-welded, and the microstructures in a horizontal plane are shown in the figures given below.

270°C (comparative example, a relative low-temperature heat treatment): Fig. 32

500°C (a high-temperature heat treatment: slow cooling was carried out after heating): Fig. 33

EXAMPLE 31

The seizure load of the samples of Table 36 was measured under the following condition in which the sliding condition was made severe by the use of a low-viscosity lubricating oil. The number of silicon particles from 2 to 5 microns in size of Samples EB1 through ED3 was not measured.

TABLE 36

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	8 wt% Size of Si Particles (μm) <5	5 ~ 10	10< ~ 20	20< ~ 40	Pb (wt%)	Cu (wt%)	Cr (wt%)
1	bal	98	0	0	0	4	0.5	0.5
2	bal	354	0	0	0	4	0.5	0.4
3	bal	629	0	0	0	4	0.5	0.4
1	bal	—	5	0	0	4	0.5	0.4
2	bal	—	38	0	0	4	0.5	0.4
3	bal	—	115	0	0	4	0.5	0.4
1	bal	—	123	7	0	4	0.5	0.4
2	bal	—	82	28	0	4	0.5	0.4
3	bal	—	73	62	0	4	0.5	0.4
1	bal	—	62	23	3	4	0.5	0.4
2	bal	—	34	18	9	4	0.5	0.4
3	bal	—	29	19	13	4	0.5	0.4

The results are shown in Fig. 34. The abscissa of Fig. 34 indicates the number of the largest-sized silicon particles of the samples. The samples were divided into five groups of EA to ED, in accordance with the four ranges of the largest-sized silicon particles. As is apparent from Fig. 34, the seizure load was influenced by the number of the largest-sized silicon particles and was virtually not influenced by the number of the smaller-sized silicon particles.

Considering the above, the present inventors propose a limitation of at least five silicon particles at least 5 microns in size.

EXAMPLE 22

The seizure load and the fatigue strength of the samples shown in Table 36 (1) were measured under Condition A' and Condition B', respectively. The amount of wear was also measured.

The results are given in Table 37 (2). As is apparent from this table, in accordance with the present invention, the seizure resistance and wear resistance were enhanced and the fatigue resistance was not decreased appreciably due to coarse Si particles.

TABLE 37 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Composition / Samples	Al	Number of Si Particles (5 wt%Si) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cu	Cr
E1	bal	—	5	0	0	4	0.5	0.4
E2	bal	—	83	7	0	4	0.5	0.4
E3	bal	—	64	34	13	4	0.5	0.4
E4	bal	—	46	0	0	4	0.5	0.4
E5	bal	—	73	25	0	4	0.5	0.4

TABLE 37 (2)

Test Results

Performance / Samples	Seizure Load (kg-cm²) Test Conditions A'	Fatigue Load (kg/cm²) Test Conditions B
E1 (comparative examples)	600	750
E2	800	700
E3	950	650
E4	650	700
E5	850	650

EXAMPLE 33

Samples having a silicon content of 7% were subjected to the same experiments as those in Example 32, and the results given in Tables 38 (1) and 38 (2) were obtained. The results were virtually the same as those in Example 32.

TABLE 38 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	Al	Number of Si Particles (7 wt%Si) <5μm	5 ~ 10μm	10< ~ 20 μm	20< ~ 40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
E6	bal	—	6	0	0	4	0.5	0.4
E7	bal	—	96	8	0	4	0.5	0.4
E8	bal	—	66	38	16	4	0.5	0.4
E9	bal	—	56	0	0	4	0.5	0.4
E10	bal	—	61	29	0	4	0.5	0.4

TABLE 38 (2)

Test Results

Samples	Seizure Load (kg-cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B
E6	600	600
E7	800	550
E8	950	500
E9	700	600
E10	800	650

EXAMPLE 34

Sample having a silicon content of 9% were subjected to the same experiments as those in Example 32. The results are given in Tables 39 (1) and 39 (2). The results were virtually the same as those in Example 32.

TABLE 39 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Composition / Samples	Al	Number of Si Particles (9 wt%Si) <5 μm	5 ~ 10 μm	10 ~ 20 μm	20 ~ 40 μm	Pb	Cu	Cr
E11	bal	—	10	0	0	4	0.5	0.4
E12	bal	—	95	12	0	4	0.5	0.4
E13	bal	—	53	42	20	4	0.5	0.4
E14	bal	—	72	45	0	4	0.5	0.4
E15	bal	—	125	0	0	4	0.5	0.4

TABLE 39 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
E11	650	600
E12	800	500
E13	950	450
E14	850	500
E15	700	550

EXAMPLE 35

Samples having a silicon content of 11% were subjected to the same experiments as those in Example 32. The results are given in Tables 40(1) and 40(2). The results were virtually the same as those in Example 32.

TABLE 40 (1)

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Composition / Samples	Al	Number of Si Particles (9 wt%Si) <5 μm	5 ~ 10 μm	10 ~ 20 μm	20 ~ 40 μm	Pb	Cu	Cr
E16	bal	—	16	0	0	4	0.5	0.4
E17	bal	—	93	26	0	4	0.5	0.4
E18	bal	—	78	51	25	4	0.5	0.4
E19	bal	—	129	0	0	4	0.5	0.4
E20	bal	—	97	48	0	4	0.5	0.4

TABLE 40 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
E16	650	500
E17	850	450
E18	950	350
E19	700	450
E20	800	400

EXAMPLE 36

As is shown in Table 41, the distribution of the silicon particles of the samples was made constant and the silicon content was varied. The seizure resistance of the samples was measured under Condition A′ and the results are shown in Fig. 35. The fatigue strength was measured under Condition B′, and the results are shown in Fig. 36.

COMP—E in Fig. 35 indicates a comparative example in which an aluminum alloy containing 4%Pb, 0.5%Cu, 0.4%Cr, and up to 10% of Si was heat-treated at 350°C before being pressure-welded.

TABLE 41

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

		Si (wt%)							
		Size of particles	<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm			
Samples	Al	Number	bal	33 ~ 38	10 ~ 13	2 ~ 4	Pb (wt%)	Cu (wt%)	Cr (wt%)
E21 (Comparative Samples)	bal			0.5			4	0.5	0.4
E22 (Comparative Samples)	bal			1			4	0.5	0.4
E23 (Comparative Samples)	bal			3			4	0.5	0.4
E24	bal			5			4	0.5	0.4
E25	bal			7			4	0.5	0.4
E26	bal			9			4	0.5	0.4
E27	bal			11			4	0.5	0.4
E28	bal			13			4	0.5	0.4
E29	bal			15			5	0.5	0.4

As is apparent from Fig. 35, the seizure load reaches a maximum value when the silicon content was approximately 8%. As was mentioned above, the seizure resistance is attained according to the present invention by the fact that the silicon particles realize a special conformability and support a shaft. Since in the present example the distribution of silicon particles 5 microns or more in size is maintained constant, the contribution of the special conformability to the seizure resistance is believed to be constant notwithstanding the silicon content. However, the seizure load, i.e., the seizure resistance, is the highest at a silicon content of approximately 6% because the effects of fine silicon particles less than 5 microns in size are most outstanding and strongly support the coarse silicon particles in the aluminum matrix. When the silicon content is more than approximately 6%, the reliability of the aluminum matrix, especially the reliability of the dynamic behavior of the aluminum matrix, is poor and the fatigue phenomenon is prominent, with the result that the strength of the aluminum matrix is lowered and thus the seizure resistance of the entire alloy is lowered.

As is apparent from Fig. 36, when the silicon content exceeds 5%, the fatigue resistance is low because of the presence of the above-described fine particles.

The amount of wear of samples E21 through E29, the size of the silicon particles of which was controlled, and the comparative samples was measured under Condition G. The results are shown in Fig. 37. As is apparent from Fig. 37, when the size of the silicon paticles of the samples was controlled by the high-temperature heat treatment according to the present invention, the wear resistance of the aluminum alloy containing lead and the like was enhanced.

EXAMPLE 37

The seizure load, fatigue strength, and amount of wear of sample in which different kinds of lead and the like, copper and the like, and chromium were varied were measured. The results are given in Tables 40(1) through 44(2). As is apparent from these tables, the control of coarse silicon particles according to the present invention makes it possible to obtain aluminum alloys containing various kinds of additional elements and having excellent bearing characteristics.

TABLE 42 (1)

Composition of Aluminum Alloy Samples and Distribution Silicon Particles

wt%

Composition		Number of Si Particles (5 wt%Si)											
Samples	Al	<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cd	In	Tl	Bi	Cw	Mg	Cr or Mn
E30	bal	—	5	0	0	—	—	—	—	8	2	—	—
E31	bal	—	49	23	0	—	—	3	—	—	—	1	0.5
E32	bal	—	43	31	8	1	—	—	—	—	—	—	—
E33	bal	—	127	0	0	—	4	—	—	—	1	—	—
E34	bal	—	93	7	0	0.5	—	—	—	—	0.3	—	0.5*

* Manganese

TABLE 42 (2)

Test Results

Performance Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
E30	600	550
E31	700	700
E32	850	500
E33	700	550
E34	750	700

TABLE 43 (1)

Composition of Aluminum Alloy Samples and Distribution Silicon Particles

wt%

		Number of Si Particles (8 wt%Si)											
Samples	Al	<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cd	In	Tl	Bi	Cw	Mg	Cr or Mn
E35	bal	bal	5		0	—	—	—	—	3	—	—	0.1
E36	bal	bal	67	38	0	—	—	—	2	—	—	—	0.3*
E37	bal	bal	52	26	11	4	—	—	—	—	—	—	—
E38	bal	bal	98	6	0	3	—	—	—	—	0.1	—	0.5
E39	bal	bal	155	0	0	—	—	2	—	—	0.5	—	—

*manganese

TABLE 43 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
E35	600	400
E36	750	500
E37	950	300
E38	850	450
E39	800	400

TABLE 44 (1)

Composition of Aluminum Alloy Samples and Distribution Silicon Particles

wt%

Samples	Al	Number of Si Particles (11 wt%) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cd	In	Tl	Bi	Cw	Mg	Cr
E40	bal	bal	5	0	0	3	—	2	—	—	—	2	1
E41	bal	bal	88	41	0	6	—	—	—	—	0.8	—	0.5

TABLE 44 (2)

Test Results

Samples	Seizure Load (kg/cm^2) Test Conditions A'	Fatigue Load (kg/cm^2) Test Conditions B'
E11	650	450
E12	700	400

EXAMPLE 38

(1) Influence of Temperature of Lubricating Oil

The seizure load of sample EC2 and a 4%Pb-1%Cu-Al alloy as the comparative example (COMP) was measured under Condition A', in which the temperature of the lubricating oil was 80°C and 140°C. The results are shown in Table 45.

TABLE 45

Seizure Load (kg/cm^2)

Samples	Oil Temperature (°C) 80	140
EC2	1,100	900
Comparative Example	1,000	300

It is seen that, the:e was an extremely large difference in the seizure load between the material of the present invention and that of the comparative example at a high temperature.

(2) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at An he Oil Temperature of 1 *0°C

The seizure load of sample EC2 and a 20%Sn-1%Cu-Al alloy as a comparative example was measured under Condition A', in which the oil temperature was 140°C. The results are given in the following table.

TABLE 46

Seizure Load (kg/cm²)

	EC2	Comparative Example
Forged Shaft	approx. 1,350	approx. 1,000
FCD70	approx. 900	approx. 250

When the opposed member was a forged shaft, there was no great difference in the seizure load between the material of the present invention and the material of the comparative example, but there was a very great difference when the opposed member was made of nodular graphite cast iron.

(3) Wear Resistance

The amount of wear of sample EC2 was measured under the above-described condition.

For the purpose of comparison the amount of wear of a 4%Pb-1%Cu-Al alloy — COMPE — free of Si and a 8%Si-1%Cu-Al alloy — COMPD(2) was measured under Condition C. The results are shown in Fig. 38. Wear of the comparative materials increased with the passage of time, but wear of the material according to the present invention virtually ceased after 4 hours. The present inventors believe this difference is as follows. The comparative material, mainly the softs tin phase thereof, are uninterruptedly shaved off by the opposed member, i.e., a shaft, and the comparative materials thus wear out uninterruptedly. On the other hand, the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during an initial sliding period by coarse silicon particles which are present on the surface of a bearing. As a result, the shaft undergoes such a change that its surface may bring about an advantageous sliding condition between the shaft and bearing, such condition being virtual fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping the wearing thereof.

EXAMPLE 39

An aluminum alloy containing 8%Si, 4% Pb, 0.5%Cu, and 0.4%Cr was subjected to annealing at the temperatures given below before being pressure-welded. The microstructures in the horizontal plane were observed.

270°C (comparative example, a low-temperature heat treatment)

500°C (slow cooling was carried out after heating)

It was revealed that flat silicon particles were nodularized.

EXAMPLE 40

Table 47 shows the aluminum-alloy compositions of and the hard-particle distributions of the samples.

TABLE 47

Composition of Aluminum Alloy Samples and Distribution of Hard Particles and Distribution of Hard Particles

Samples		Al	Mn content (wt%)	Hard Particles (μm) 2 ~ <5	5 ~ 10	10< ~ 20	20< ~ 30	30< ~ 40	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
	1	bal	3	about 163	0	0	0	0	15	3	0.5	0.4
FA	2	bal	3	about 301	0	0	0	0	15	3	0.5	0.4
	3	bal	3	about 442	0	0	0	0	15	3	0.5	0.4
	1	bal	3	bal	5	0	0	0	15	3	0.5	0.4
FB	2	bal	3	bal	31	0	0	0	15	3	0.5	0.4
	3	bal	3	bal	85	0	0	0	15	3	0.5	0.4
	1	bal	3	bal	34	5	0	0	15	3	0.5	0.4
FC	2	bal	3	bal	30	11	0	0	15	3	0.5	0.4
	3	bal	3	bal	39	26	0	0	15	3	0.5	0.4
	1	bal	3	bal	24	13	6	0	15	3	0.5	0.4
FD	2	bal	3	bal	29	18	10	0	15	3	0.5	0.4
	3	bal	3	bal	22	18	16	0	15	3	0.5	0.4
FE	1	bal	3	bal	31	15	7	4	15	3	0.5	0.4

The seizure load of the samples given in Table 47 was tested under Condition A.

The results are shown in Fig. 39. The abscissa of Fig. 39 indicates the number of the largest-sized silicon particles of the samples. The samples were divided into five groups of FA to FE in accordance with the five ranges of the largest-sized silicon particles. The following facts are apparent from Fig. 39. (A) The seizure load was influenced by the number of the largest-sized silicon particles and was virtually not influenced by the number of the smaller-sized silicon particles. (B) The seizure load increases with the increase in the number of the largest-size silicon particles. Samples other than group FA which includes greater silicon particles than those of group FA exhibit greater increases in the seizure load than in the samples of the group FA.

Considering the above-mentioned facts (A) and (B), the present inventors propose a limitation of at least five silicon particles at least 5 microns in size.

EXAMPLE 41

The seizure load and fatigue strength of samples shown in Table 48(1) were measured under the Conditions A and B, respectively.

The results are given in Table 48(2). As is apparent from this table, in accordance with the present invention, the seizure resistance and wear resistance were enhanced and the fatigue resistance was not decreased appreciably due to coarse particles.

The number of silicon particles less than 5 microns in size was not measured and thus is not given in Table 48(1).

Since the opposed member (a shaft) is made of a carbon steel for machine and construction use (S55C), the bearing alloy according to the present invention is effective as such an opposed member, the carbon of which member is present not as graphite.

TABLE 48 (1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

		Size of Hard Particles (0.5 wt%Mn)							
Samples	Al	<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
F1 (Comparative Samples)	bal	—	0	0	0	15	3	0.5	0.4
F2 (Comparative Samples)	bal	—	3	0	0	15	3	0.5	0.4
F3	bal	—	5	0	0	15	3	0.5	0.4
F4	bal	—	10	0	0	15	3	0.5	0.4
F5	bal	—	25	0	0	15	3	0.5	0.4
F6	bal	—	11	5	0	15	3	0.5	0.4
F7	bal	—	13	7	1	15	3	0.5	0.4
F8	bal	—	4	1	0	15	3	0.5	0.4

TABLE 48 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
F1 (Comparative Samples)	400	900
F2 (Comparative Samples)	450	900
F3	550	900
F4	550	900
F5	600	900
F6	650	900
F7	750	850
F8	550	900

EXAMPLE 42

Samples having a manganese content of 1% were subjected to the same experiments as those in Example 41, and the results given in Tables 49(1) and 49(2) were obtained. The results were virtually the same as those in Example 41.

TABLE 49 (1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Size of Hard Particles (0.1 wt%Mn)				Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
		<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm				
F9 (Comparative Samples)	bal	—	0	0	0	15	3	0.5	0.4
F10 (Comparative Samples)	bal	—	2	0	0	15	3	0.5	0.4
F11	bal	—	5	0	0	15	3	0.5	0.4
F12	bal	—	13	0	0	15	3	0.5	0.4
F13	bal	—	33	0	0	15	3	0.5	0.4
F14	bal	—	25	5	0	15	3	0.5	0.4
F15	bal	—	16	8	2	15	3	0.5	0.4
F16	bal	—	3	2	0	15	3	0.5	0.4

TABLE 49 (2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A′	Fatigue Load (kg/cm²) Test Conditions B′
F9 (Comparative Samples)	400	850
F10 (Comparative Samples	500	850
F11	650	850
F12	700	850
F13	750	850
F14	800	850
F15	900	800
F16	650	850

EXAMPLE 43

Samples having a manganese content of 3% were subjected to the same experiments as those in Example 42. The results are given in Tables 50(1) and 50(2). The results were virtually the same as those in Example 42.

TABLE 50 (1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Size of Hard Particles (3 wt%Mn) <5 μm	5 ~ 10 μm	10 ~ 20 μm	20 ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
F17 (Comparative Samples)	bal	—	0	0	0	15	3	0.5	0.4
F18 (Comparative Samples)	bal	—	3	0	0	15	3	0.5	0.4
F19	bal	—	5	0	0	15	3	0.5	0.4
F20	bal	—	34	0	0	15	3	0.5	0.4
F21	bal	—	64	6	0	15	3	0.5	0.4
F22	bal	—	42	21	5	15	3	0.5	0.4
F23	bal	—	108	15	0	15	3	0.5	0.4
F24	bal	—	3	2	0	15	3	0.5	0.4

TABLE 50 (2)

Test Results

Samples	Seizure Load (kg/cm^2) Test Conditions A	Fatigue Load (kg/cm^2) Test Conditions B
F17 (Comparative Samples)	400	750
F18 (Comparative Samples)	500	750
F19	650	750
F20	750	750
F21	850	750
F22	1,100	700
F23	1,000	750
F24	700	750

EXAMPLE 44

Samples having the manganese content of 11% were subjected to the same experiments as those in Example 41. The results are given in Tables 51(1) and 51(2). The results were virtually the same as those in Example 41.

TABLE 51 (1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Size of Hard Particles (11 wt%Mn) <5 μm	5 ~ 10 μm	10 ~ 20 μm	20 ~ 40 μm	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
F25 (Comparative Samples)	bal	—	0	0	0	15	3	0.5	0.4
F26 (Comparative Samples)	bal	—	2	0	0	15	3	0.5	0.4
F27	bal	—	5	0	0	15	3	0.5	0.4
F28	bal	—	34	0	0	15	3	0.5	0.4
F29	bal	—	89	0	0	15	3	0.5	0.4
F30	bal	—	63	31	0	15	3	0.5	0.4
F31	bal	—	54	21	8	15	3	0.5	0.4
F32	bal	—	175	0	0	15	3	0.5	0.4

TABLE 51 (2)

Test Results

Samples)	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
F25 (Comparative Sample)	400	650
F26 (Comparative Samples)	500	650
F27	600	650
F28	650	600
F29	700	550
F30	750	450
F31	800	400
F32	750	500

EXAMPLE 45

The seizure load of sample FC2 of Example 40 was tested under Condition A. However, in this test, the surface roughness of the opposed member, i.e., a nodular graphite cast iron shaft, was varied. For the purpose of comparison, the seizure load of the 20%Sn-1%Cu-Al alloy (COMP) was measured. The results are shown in Fig. 40. It is evident from Fig. 40 that the seizure load of the present invention is excellent no matter what the surface roughness of the opposed member is. The material of the comparative example includes virtually no crystallized hard particles, and the soft Sn phases of such material have the conformability according to the general concept and provide an Al alloy with seizure resistance. Therefore, Fig. 40 hints at the differences between the effects of the special the conformability upon the seizure resistance and those of conformability according to the general concept. Since the opposed member is made of nodular graphite cast iron, it can be well understood that the material according to the present invention has a high seizure resistance against nodular graphite cast iron.

EXAMPLE 46

As is shown in Table 52, the distribution of hard particles was maintained constant, and the content of every element of manganese and the like was varied. The seizure resistance of the samples was measured under Condition A, and the results are shown in Fig. 41. The fatigue strength was measured under Condition B, and the results are shown in Fig. 42.

TABLE 52

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

		Content of Manganese or the like (wt%)								
		Size of particles	<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm				
Samples	Al	Number	bal	30 ~ 35	8 ~ 11	2 ~ 4	Sn (wt%)	Pb (wt%)	Cu (wt%)	Cr (wt%)
F33	bal		0.5				15	3	0.5	0.4
F34	bal		1				15	3	0.5	0.4
F35	bal		3				15	3	0.5	0.4
F36	bal		5				15	3	0.5	0.4
F37	bal		7				15	3	0.5	0.4
F38	bal		9				15	3	0.5	0.4
F39	bal		11				15	3	0.5	0.4
F40	bal		13				15	3	0.5	0.4
F41	bal		15				15	3	0.5	0.4

As is apparent from Fig. 41, the seizure load reaches the maximum value when the content of manganese and the like is approximately 4%. As was mentioned above, the seizure resistance is attained according to the present invention by the fact that the silicon particles realize the special conformability and support a shaft. In the present example, in which the distribution of particles 5 microns or more in size is maintained constant, the content of manganese and the like exerts some influence on the seizure load. This is believed to be due to fine hard particles less than 5 microns in size.

As is apparent from Fig. 42, when the content of manganese and the like exceeds 5%, the fatigue resistance is low. This is also believed to be due to fine hard particles less than 5 microns in size.

EXAMPLE 47

Samples in which different kinds of lead and the like and copper and the like were varied were subjected to the same experiments as those in Examples 41, 42, 43, and 44. The results are given in Tables 53(1) and 53(2). As is apparent from these tables, a satisfactory seizure load and fatigue strength can be obtained when various kinds of optional elements are used.

TABLE 53 (1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles (0.5 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F42	bal	Mn	—	5	0	0	5	—	—	0.5	—	—	0.8	—	—
F43	bal	Fe	—	18	3	0	30	—	—	—	1	—	1	—	1
F44	bal	Mo	—	12	0	0	3	—	—	—	—	—	—	—	—
F45	bal	0.1%Ni 0.4%Sb	—	13	8	0	10	—	—	1	—	—	—	—	—
F46	bal	Zr	—	9	4	1	20	—	—	—	—	—	0.5	—	0.3*
F47	bal	Cr	—	21	0	0	1.5	—	—	—	—	—	—	2	—
F48	bal	Ti	—	6	1	0	15	3	—	—	—	—	—	—	—
F49	bal	Sb	—	20	5	0	35	—	2	—	—	—	2	—	0.1
F50	bal	Nb	—	30	0	0	10	—	—	—	—	—	—	—	0.5

* Manganese

TABLE 53 (1) (continued)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles (1 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F51	bal	Mn	—	15	5	0	13	3	—	—	—	—	0.5	—	—
F52	bal	Fe	—	5	0	0	5	—	—	—	—	—	—	—	0.8
F53	bal	Mo	—	9	2	1	15	—	—	—	1	—	—	—	0.3
F54	bal	Ni	—	23	11	3	25	0.5	—	—	—	—	—	—	—
F55	bal	0.5%Zr 0.5%Fe	—	28	13	0	10	—	—	—	—	—	—	—	—
F56	bal	Co	—	31	8	4	15	—	—	—	—	—	1	—	0.5
F57	bal	Cr	—	11	0	0	30	—	—	—	—	—	1	—	—
F58	bal	Sb	—	23	0	0	10	—	—	—	—	5	—	—	0.8*
F59	bal	Nb	—	41	5	0	15	—	—	—	—	—	0.5	—	—

* Manganese

TABLE 53 (1) (continued)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles (3 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F60	bal	0.5%Zr 0.2%Mn 2.3%Ti	bal	30	11	4	1.5	—	—	—	—	—	—	—	—
F61	bal	Fe	bal	44	21	0	20	—	5	—	—	—	—	—	—
F62	bal	Mo	bal	5	0	0	10	—	—	—	2	—	—	0.5	—
F63	bal	Ni	bal	37	0	0	15	2	—	—	—	—	1	—	0.3*
F64	bal	Zr	bal	13	5	1	10	—	3	—	—	—	0.1	—	—
F65	bal	Co	bal	21	8	0	5	—	—	—	—	—	0.2	—	—
F66	bal	Ti	bal	8	3	1	15	—	—	—	2	—	—	—	—
F67	bal	Sb	bal	52	0	0	30	—	—	—	—	—	—	0.4	0.2
F68	bal	Cr	bal	33	5	0	25	—	—	—	—	5	—	2	—

* Manganese

TABLE 53 (1) (continued)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles (5 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F69	bal	Mn	bal	43	18	0	15	—	—	—	—	—	—	—	0.1
F70	bal	Fe	bal	95	0	0	6	1	—	—	—	—	—	—	—
F71	bal	1%Co 1%Mo 3%Nb	bal	21	3	0	30	—	—	—	—	—	2	—	—
F72	bal	Cr	bal	5	0	0	20	—	—	—	—	—	—	—	—
F73	bal	Zr	bal	31	5	1	10	—	—	—	3	—	1	—	0.5
F74	bal	Co	bal	49	21	8	15	—	—	—	—	—	0.8	—	1*
F75	bal	Ti	bal	20	8	2	25	—	—	—	—	—	—	—	1
F76	bal	Sb	bal	59	6	0	17	3	—	—	—	—	1	—	—
F77	bal	Nb	bal	43	0	0	15	—	—	2	—	—	—	—	0.5

* Manganese

TABLE 53 (1) (continued)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles 7 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F78	bal	Mn	bal	24	11	2	15	—	—	—	—	—	1.5	—	—
F79	bal	Fe	bal	39	0	0	30	—	—	—	—	3	—	1	0.8
F80	bal	Mo	bal	83	31	0	10	4	—	—	—	—	—	—	—
F81	bal	Ni	bal	41	25	0	20	—	—	—	—	—	1.5	—	0.5*
F82	bal	Zr	bal	5	0	0	15	—	—	—	—	—	—	—	0.3
F83	bal	Co	bal	23	5	0	25	—	—	—	—	—	—	—	—
F84	bal	Ti	bal	106	0	0	5	—	—	—	—	1	2	—	—
F85	bal	6.5%Sb 0.5%Ti	bal	63	21	8	10	—	3	—	—	—	—	—	0.5
F86	bal	Nb	bal	42	29	13	15	3	—	—	—	—	—	—	0.5

* Manganese

TABLE 53 (1) (continued)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	Hard Particles (11 wt%Mn ~ Nb) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Sn	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr or Mn
F87	bal	Mn	bal	46	28	21	25	—	—	—	—	—	0.2	—	0.2
F88	bal	1.5%Zr 9%Fe 0.5%Co	bal	93	28	0	35	—	—	—	—	—	—	—	—
F89	bal	Cr	bal	115	0	0	15	—	—	—	—	—	—	—	0.7
F90	bal	Ni	bal	33	15	5	10	2	—	—	2	—	0.8	—	0.3
F91	bal	Zr	bal	213	0	0	5	—	—	—	—	—	—	—	—
F92	bal	Co	bal	94	42	18	35	—	—	—	—	8	—	—	—
F93	bal	Ti	bal	44	15	0	10	1	—	—	—	—	0.5	0.3	0.6*
F94	bal	Sb	bal	5	0	0	20	—	6	—	—	—	1	1	—
F95	bal	Nb	bal	131	4	0	15	—	—	—	—	—	—	1	—

* Manganese

TABLE 53 (2)

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
F42	550	700
F43	750	800
F44	600	700
F45	750	650
F46	800	850
F47	650	700
F48	650	700
F49	750	800
F50	700	900
F51	700	650
F52	550	850
F53	850	800
F54	900	600
F55	800	600
F56	900	750
F57	700	650
F58	700	850
F59	750	600
F60	1,050	550
F61	900	600
F62	600	600
F63	700	800
F64	950	550
F65	850	600
F66	900	550
F67	750	800
F68	800	600
F69	950	750
F70	800	550
F71	800	600

TABLE 53 (2) (continued)

Samples	Seizure Load (kg/cm²) Test Conditions A	Fatigue Load (kg/cm²) Test Conditions B
F72	650	600
F73	1,000	750
F74	1,100	700
F75	1,000	750
F76	900	600
F77	700	800
F78	1,050	550
F79	700	700
F80	900	550
F81	900	650
F82	700	700
F83	800	550
F84	750	550
F85	1,100	600
F86	1,100	400
F87	800	400
F88	800	400
F89	600	650
F90	800	450
F91	700	450
F92	1,100	400
F93	800	550
F94	700	450
F95	750	500

EXAMPLE 48

The following experiments were carried out using a sample given in Table 47.

(1) Influence of Temperature of Lubricating Oil

The seizure load of sample FC2 and a 20% Sn-1%Cu-Al alloy as the comparative example was measured under Condition A, in which the oil temperature was 80°C and 140°C. The results are given in Table 54.

TABLE 54

Seizure Load

	Oil Temperature (°C)	
Sample	80	140
FC2	1,100	830
Comparative Example	400	250

As is apparent from Table 54, there was an extremely large difference in the seizure load between the material of the present invention and that of the comparative example at a high temperature.

(2) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at an Oil Temperature of 140°C

The seizure load of sample FC2 and a 20%Sn-1%Cu-Al alloy as a comparative example was measured under Condition A, in which the oil temperature was 140°C. The results are given in the Table 55.

TABLE 55

Seizure Load (kg/cm²)

	FC2	Comparative Example
Forged Shaft	approx. 900	approx. 900
FCD70 Shaft	approx. 800	approx. 400

The difference in seizure load between the material of the present invention and the material of the comparative example was not great when the opposed member was a forged shaft. However, the difference was extremely great when the opposed member was nodular graphite cast iron (DCI).

(3) Wear Resistance

For the purpose of comparison, the amount of wear of sample FC2 and the 20% Sn-1%Cu-Al alloy was measured under Condition G'.

Condition G'

Tester:

Mixed lubrication tester

Conditions:

Opposed member (a shaft): FCD70

Surface roughness of shaft: from 0.8 to 0.9 μmRz

Lubricating oil: liquid paraffin

Rotation of shaft: 100 rpm

Diameter of shaft· 40 mmφ

Hardness of shaft: from 200 to 300 Hv

Load: 25 kg

Length of test: 5 hours

The results are show in Fig. 43. Wear of the comparative material increased with the passage of time, but wear of the material according to the present invention virtually ceased after one hour. The present inventors believe this difference is as follows.

In the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during an initial sliding period by coarse hard particles which are present on the surface of a bearing. As a result, the shaft und rgo s such a change

that its surface may bring about an advantageous sliding condition between the shaft and bearing, such condition being virtual fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping the wearing thereof.

EXAMPLE 49

Aluminum alloys of comparative samples which contained 15%Sn, 3%Pb, 0.5%Cu, 0.4%Cr, and varied contents of manganese and the like were subjected to a bearing production step but were annealed at 350°C before being pressure-welded. The seizure load of the comparative samples was measured under Condition A. The results are shown in Fig. 44. As is apparent from a comparison of Fig. 44 and Fig. 41, when the high-temperature heat treatment according to the present invention is carried out, the seizure resistance is considerably enhanced.

The amount of wear of samples according to the present invention and the comparative samples was measured under Condition C.

The results are shown in Fig. 45. As is apparent from this drawing, the high-temperature heat treatment according to the present invention, attains control of the size of the silicon particles and considerably enhances the wear resistance of the tin-containing aluminum alloy.

EXAMPLE 50

An aluminum, alloy containing 8%Si, 15%Sn, 3%Pb, 0.5%Cu, and 0.4%Cr was subjected to annealing at the temperatures given below before being pressure-welded, and the microstructures in a horizontal plane are shown in the figures given below.

270°C (comparative example, a relatively low-temperature heat treatment): Fig. 46

500°C (slow cooling was carried out after heating): Fig. 47

As is apparent from these figures, the flat particles were nodularized.

EXAMPLE 51

Table 56 shows the aluminum-alloy compositions of and the hard-particle distributions of the samples.

TABLE 56

Composition of Aluminium Alloy Samples and Distribution of Hard Particles

Samples		Al	Mn (wt%)	Hard Particles (μm) 2 ~ <5	5 ~ <10	10 ~ <20	20 ~ <40	Pb (wt%)	Cu wt%)	Cr (wt%)
GA	1	bal	5	115	0	0	0	4	0.5	0.4
	2	bal	5	283	0	0	0	4	0.5	0.4
	3	bal	5	467	0	0	0	4	0.5	0.4
GB	1	bal	5	283	5	0	0	4	0.5	0.4
	2	bal	5	152	63	0	0	4	0.5	0.4
	3	bal	5	128	94	0	0	4	0.5	0.4
GC	1	bal	5	68	34	7	0	4	0.5	0.4
	2	bal	5	42	31	24	0	4	0.5	0.4
	3	bal	5	54	35	31	0	4	0.5	0.4
GD	1	bal	5	56	43	21	8	4	0.5	0.4
	2	bal	5	39	22	18	12	4	0.5	0.4
	3	bal	5	32	28	21	18	4	0.5	0.4

The seizure load of the samples given in Table 56 was tested under the following conditions:

Condition A''

Tester:
Journal-Type Seizure-Testing Machine Conditions:
Opposed Member (a Shaft): FCD70
Lubricating oil: SAE10W-30
Surface roughness of shaft: from 0.6 to 0.8 μm Rz
Lubricating oil temperature: 160 $\pm$ 2.5°C
Rotation of shaft: 1,000 rpm
Diameter of shaft: 52 mm
Hardness of shaft: from 200 to 300 Hv
Load: 50 kg/cm^2 at the beginning and then increased every 30 minutes 50 kg/cm^2 every 30 min
Roughness of bearing: from 1 to 1.8 μm Rz
Diameter of bearing: 52 mm

The results are shown in Fig. 48. The abscissa of Fig. 48 indicates the number of the largest-sized silicon particles of the samples. The samples were divided into five groups of GA to GD in accordance with the five ranges of the largest-sized silicon particles. The following are apparent from Fig. 48:

A. The seizure load was influenced by the number of the largest-sized hard particles and was virtually not influenced by the number of the smaller-sized hard particles.

B. The seizure load increased in accordance with an increase in the number of the largest-sized hard particles. Samples other than group GA which included larger-sized silicon particles than those of groups GA exhibited a greater increase did the seizure load than in the samples of group GA.

Considering A and B, the present inventors propose a limitation of at least five hard particles at least 5 microns in size.

EXAMPLE 52

The seizure load and fatigue strength of the samples shown in Table 57(1) were measured. The fatigue strength was measured under Condition B.

TABLE 57(1)

Composition of Aluminum Alloy Samples and Distribution of Manganese Particles

Samples	Al	Number of Hard Particles (3 wt%Mn) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
G1 (Comparative Samples)	bal	—	0	0	0	4	0.5	0.4
G2 (Comparative Samples)	bal	—	3	0	0	4	0.5	0.4
G3	bal	—	5	0	0	4	0.5	0.4
G4	bal	—	39	0	0	4	0.5	0.4
G5	bal	—	83	0	0	4	0.5	0.4
G6	bal	—	92	6	0	4	0.5	0.4
G7	bal	—	67	25	4	4	0.5	0.4
G8	bal	—	93	26	0	4	0.5	0.4

The results are given in Table 57(2). As is apparent from this table, in accordance with the present invention, the seizure resistance and wear resistance were enhanced and the fatigue resistance was not decreased appreciably due to coarse hard particles.

The number of silicon particles less than 5 microns in size was not measured and thus is not given in Table 57(1).

Since the opposed member (a shaft) is made of a carbon steel for machine and construction use (S55C), the material according to the present invention is effective as such an opposed member, the carbon of which member is present not as graphite.

TABLE 57(2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A″	Fatigue Load (kg/cm²) Test Conditions B
G1 (Comparative Samples)	450	700
G2 (Comparative Samples)	500	700
G3	600	700
G4	650	700
G5	700	700
G6	750	700
G7	900	650
G8	800	650

EXAMPLE 53

Samples having a content of manganese and the like of 8% were subjected to the same experiments as those in Example 51, and the results given in Tables 58(1) and 58(2) were obtained. The results were virtually the same as those in Example 51.

TABLE 58(1)

Composition of Aluminum Alloy Samples and Distribution of Manganese Particles

Samples	Al	Number of Hard Particles (1 wt%Mn) <5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb (wt%)	Cu (wt%)	Cr (wt%)
G9 (Comparative Samples)	bal	—	0	0	0	4	0.5	0.4
G10 (Comparative Samples)	bal	—	2	0	0	4	0.5	0.4
G11	bal	—	5	0	0	4	0.5	0.4
G12	bal	—	62	0	0	4	0.5	0.4
G13	bal	—	165	7	0	4	0.5	0.4
G14	bal	—	83	32	2	4	0.5	0.4
G15	bal	—	45	23	11	4	0.5	0.4
G16	bal	—	85	33	0	4	0.5	0.4

TABLE 58(2)

Test Results

Samples	Seizure Load (kg/cm^2) Test Conditions A″	Fatigue Load (kg/cm^2) Test Conditions B
G9 (Comparative Samples)	600	650
G10 (Comparative Samples)	600	650
G11	700	600
G12	750	600
G13	800	600
G14	850	550
G15	900	500
G16	850	550

EXAMPLE 54

Samples having a content of manganese and the like of 11% were subjected to the same experiments as those in Example 52. The results are given in Tables 59(1) and 59(2). The results were virtually the same as those in Example 52.

TABLE 59(1)

Composition of Aluminum Alloy Samples and Distribution of Manganese Particles

Samples	Al	Number of Hard Particles (11 wt%Mn)				Pb	Cu	Cr
		<5 μm	5 ~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	(wt%)	(wt%)	(wt%)
G17 (Comparative Samples)	bal	—	0	0	0	4	0.5	0.4
G18 (Comparative Samples)	bal	—	3	0	0	4	0.5	0.4
G19	bal	—	5	0	0	4	0.5	0.4
G20	bal	—	58	0	0	4	0.5	0.4
G21	bal	—	123	0	0	4	0.5	0.4
G22	bal	—	98	7	0	4	0.5	0.4
G23	bal	—	95	19	2	4	0.5	0.4
G24	bal	—	45	21	18	4	0.5	0.4

TABLE 59(2)

Test Results

Samples	Seizure Load (kg/cm²) Test Conditions A″	Fatigue Load (kg/cm²) Test Conditions B
G17 (Comparative Samples)	600	500
G18 (Comparative Samples)	600	500
G19	700	500
G20	750	500
G21	800	450
G22	850	450
G23	900	400
G24	950	350

EXAMPLE 55

As is shown in Table 60, the distribution of hard particles of the samples was maintained constant, and the content of every element of manganese and the like was varied. The seizure load of the samples was measured under condition A″, and the results are shown in Fig. 49. In Fig. 49, the seizure load of the comparative samples is also shown.

Aluminum alloys of the comparative samples which contained 4%Pb, 0.5%Cu, 0.4%Cr, and varied contents of manganese and the like subjected to a bearing production step but were annealed at 350°C before being pressure-welded, and, thus the size of the hard particles was not controlled. The seizure load of the comparative samples was measured under Condition A′. The results are shown in Fig. 49. As is apparent from Fig. 49, the seizure load of the samples according to the present invention was considerably higher than that of the comparative samples.

As is apparent from Fig. 49, the seizure load saturates when the content of manganese and the like is approximately 4%. As was mentioned above, the seizure load is influenced by the number and dimension of the largest-sized hard particles when the content of manganese and the like falls within the range of the present invention. In the present example in which the distribution of particles 5 microns or more in size was maintained constant, the content of manganese and the like exerted some influence on the seizure load. This is believed to be due to fine hard particles less than 5 microns in size.

The fatigue strength was measured under Condition B, and the results are shown in Fig. 50.

As is apparent from Fig. 50, when the content of manganese and the like exceeded 4%, the fatigue resistance was low. This is also believed to be due to fine hard particles less than 5 microns in size.

TABLE 60

Composition of Aluminum Alloy Samples and Distribution of Silicon Particles

Samples	A1	Content of Manganese and the like and Hard Particles					Pb (wt%)	Cu (wt%)	Cr (wt%)
		Size of Particles Number	<5 µm bal	5 ~ 10 µm 30	10< ~ 20 µm 11	20< ~ 40 µm 3			
G25	bal		0.5	wt%			4	0.5	0.4
G26	bal		1	wt%			4	0.5	0.4
G27	bal		3	wt%			4	0.5	0.4
G28	bal		5	wt%			4	0.5	0.4
G29	bal		7	wt%			4	0.5	0.4
G30	bal		9	wt%			4	0.5	0.4
G31	bal		11	wt%			4	0.5	0.4
G32	bal		13	wt%			4	0.5	0.4
G33	bal		15	wt%			4	0.5	0.4

EXAMPLE 56

Samples in which different kinds of lead and the like and copper and the like were varied were subjected to the same experiments as those in Examples 51, 52, 53, and 54. The results are given in Tables 61(1) and 61(2). As is apparent from these tables, a satisfactory seizure load and fatigue strength are obtained when various optional elements are used.

TABLE 61(1)

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	(wt%)	Hard Particles <5 μm	5~ 10 μm	10<~ 20 μm	20<~ 40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
G34	bal	Mn	0.5	—	62	21	0	4	—	—	—	—	—	—	—
G35	bal	Fe	0.5	—	43	22	11	3	—	—	—	—	1	—	—
G36	bal	Co Zr	0.5	—	92	35	0	3	—	—	—	—	1	—	0.5*
G37	bal	Cr	0.5	—	42	13	5	—	—	—	—	4	2	—	—
G38	bal	Sb	2	—	5	0	0	2	—	—	—	—	—	—	0.8
G39	bal	Ni	2	—	45	3	0	—	—	—	—	8	—	—	—
G40	bal	Mo	2	—	136	0	0	4	—	—	—	—	0.5	—	0.5
G41	bal	Co	2	—	82	25	3	—	—	—	3	—	—	—	0.3
G42	bal	Ti Nb	2	—	46	0	0	2	—	2	—	—	—	—	—

Sample 36 contains 0.2% Co and 0.3% Zr, and Samples 42 contains 0.5% Ti and 1.5% Nb.
* Manganese

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	(wt%)	Hard Particles (1 wt% Mn ~ Nb) <5 μm	5~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
G43	bal	Mn	5	—	42	15	4	4	—	—	—	—	0.5	—	1
G44	bal	Cr	5	—	169	0	0	—	5	—	—	—	0.5	—	—
G45	bal	Zr	5	—	5	0	0	—	—	0.5	—	—	—	—	—
G46	bal	Ti	5	—	89	35	0	6	—	—	—	—	—	—	0.8
G47	bal	Mn, Fe Sb	5	—	113	4	0	—	—	—	2	—	0.1	—	—
G48	bal	Ni	7	—	69	34	13	—	—	1	—	—	—	—	—
G49	bal	Mo	7	—	45	31	18	—	5	—	—	—	—	—	—
G50	bal	Co	7	—	51	25	0	—	—	—	—	3	2	—	1*
G51	bal	Nb	7	—	16	0	0	—	8	—	—	—	2	—	1

Sample G47 contains 1% Mn, 1% Fe, and 3% Sb.

Composition of Aluminum Alloy Samples and Distribution of Hard Particles

Samples	Al	Additional Elements	(wt%)	Hard Particles (3 wt% Mn ~ Nb) <5 μm	5~ 10 μm	10< ~ 20 μm	20< ~ 40 μm	Pb	Cd	In	Tl	Bi	Cu	Mg	Cr Mn
G52	bal	Mn	7	bal	32	0	0	4	—	—	—	—	—	0.5	—
G53	bal	Fe	9	bal	93	27	0	3	—	—	—	—	—	—	—
G54	bal	Zr	9	bal	118	35	2	—	3	—	—	—	—	—	0.4
G55	bal	Nb, Zr Ti	9	bal	63	5	0	4	—	1	—	—	0.8	—	—
G56	bal	Sb	9	bal	85	0	0	2	—	—	—	—	0.8	—	0.2
G57	bal	Ni	9	bal	58	35	18	3	1	—	—	—	—	2	—
G58	bal	Mo	11	bal	183	0	0	0.5	—	—	—	—	0.1	—	0.1
G59	bal	Cr	11	bal	96	45	0	1	—	—	—	—	—	—	—
G60	bal	Nb	11	bal	43	31	15	—	4	—	—	—	1.5	—	—

Sample G55 contains 6% Nb, 1% Zr, and 2% Ti.

TABLE 61(2)—1

Samples	Seizure Load (kg/cm^2) Test Conditions A″	Fatigue Load (kg/cm^2) Test Conditions B
G34	500	600
G35	600	600
G36	550	800
G37	600	600
G38	600	750
G39	700	500
G40	700	700
G41	900	650
G42	650	500

TABLE 61(2)—2

Samples	Seizure Load (kg/cm^2) Test Conditions A″	Fatigue Load (kg/cm^2) Test Conditions B
G43	950	700
G44	700	500
G45	650	500
G46	800	550
G47	750	400
G48	850	350
G49	950	350
G50	850	550
G51	700	600

TABLE 61(2)—3

Samples	Seizure Load (kg/cm²) Test Conditions A″	Fatigue Load (kg/cm²) Test Conditions B
G52	750	350
G53	800	300
G54	900	400
G55	800	300
G56	750	400
G57	950	300
G58	750	350
G59	850	300
G60	900	300

EXAMPLE 57

The samples given in Table 56 were subjected to the following experiments:

(1) Influence of Temperature of Lubricating Oil temperature

The seizure load of sample GC2 was measured under Condition A″, in which the temperature of the lubricating oil was 80°C and 140°C. For the purpose of comparison, the seizure load of a 4%Pb-1%Cu-Al alloy was measured. The results are given in Table 62.

As is apparent from Table 62, there was an extremely great difference in the seizure load between the material of the present invention and the material of the comparative example at a high temperature.

TABLE 62
Seizure Load (kg/cm²)

Samples	Oil Temperature (°C) 80	160
GC2	1,100	800
Comparative Example	1,000	200

(2) Influence of the Opposed Members (a Forged Shaft and a Nodular Graphite Cast Iron Shaft) at an Oil Temperature of 140°C.

The seizure load of sample GC2 and a 20%Sn-1%Cu-Al alloy as a comparative example was measured under Condition A″, in which the oil temperature was 140°C. The results are given in table 63.

There was no great difference in the seizure load between the materials of the present invention and the comparative example when the opposed member was a forged shaft. However, the difference was great when the opposed member was made of nodular graphite cast iron (FCD 70).

TABLE 63
Seizure Load (kg/cm²)

	GC2	Comparative Example
Forged Shaft	approx. 1,000	approx. 1,000
GCD70	approx. 850	approx. 300

(3) Wear Resistance

The amount of wear of sample GC2 was measured under Condition C.

For the purpose of comparison the amount of wear of a 6%Pb-1%Cu-Al alloy free of Si was measured under Condition C. The results are shown in Fig. 51. Wear of the comparative materials increased with the passage of time, but wear of the material according to the present invention virtually ceased after one hour. The present inventors believe this difference is as follows. The comparative material, mainly the soft tin phase thereof, are uninterruptedly shaved off by the opposed member, i.e., a shaft, and the comparative materials thus wear out uninterruptedly. On the other hand, in the material of the present invention, the convex surface roughness of the opposed member, i.e., a shaft, and burrs, edges, and the like which are formed around the nodular graphite present on the surface of the opposed member are worn off or shaved off during an initial sliding period by coarse hard particles which are present on the surface of a bearing. As a result, the shaft undergoes such a change that its surface may bring about an advantageous sliding condition between the shaft and bearing, such condition being virtual fluid lubrication, impeding direct contact between the shaft and bearing and thus stopping the wearing thereof.

EXAMPLE 58

Aluminum alloys of comparative samples which contained 4%Pb, 0.5%Cu, 0.4%Cr, and varied contents of silicon, were subjected to a bearing production step but were annealed at 350°C before being pressure-welded. The amount of wear of the comparative samples was measured under Condition G′.

Condition G′

Tester:

Mixed lubrication tester

Conditions:

Opposed member (a shaft): FCD70
Surface roughness of shaft: from 0.8 to 0.9 μmRz
Lubricating oil: liquid paraffin
Rotation of shaft: 100 rpm
Diameter of shaft: 40 mmϕ
Hardness of shaft: from 200 to 300 Hv
Load: 25 kg
Length of Test: 5 hours

The results are shown in Fig. 52.

The amount of wear of Samples G25 through G33 is also shown in Fig. 52. As is apparent Fig. 52, when the size of the hard particles of the samples was controlled by the high-temperature heat treatment according to the present invention, the wear resistance of the tin-containing alloy was enhanced.

EXAMPLE 59

An aluminum alloy containing 5%Mn, 4%Pb, 0.5%Cu, and 0.4%Cr was subjected to annealing at the temperatures given below before being pressure-welded. The microstructures in a horizontal plane were investigated and it was found that the flat hard particles were nodularized due to the high-temperature heat treatment according to the present invention.

270°C (comparative example, a relatively low-temperature heat treatment) 500°C (slow cooling was carried out after heating).

Industrial Applicability

The present invention can be applied in the automobile industry to the bearings of an internal-combustion engine. The alloy of the present invention is worked in the form of a semicircle, a thrust washer, a bush, a guide, or the like and is used as a bearing in which the alloy is bonded to a backing metal or as a solid form in which it is not bonded to a backing metal.

CLAIMS

1. An aluminum-base alloy bearing, wherein the aluminum alloy contains from 0.5% to 11% by weight of at least one hard element which is selected from the group consisting of silicon, manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium, and particles which consist of or comprise said hard element and which are not less than 5 microns and not more than 40 microns in size when the lengthwise diameter thereof is measured present at least five per 3.56×10^{-2} mm^2 at an optional part of the alloy.

2. An aluminum-base alloy bearing according to claim 1, wherein said hard element is from 0.5% to 5% of silicon.

3. An aluminum-base alloy bearing according to claim 2, wherein from 0.1% to 2.0% by weight of at least one element selected from the group consisting of Cu and Mg, is further contained.

4. An aluminum-base alloy bearing according to claim 2, wherein from 0.1% to 2.0% by weight of at least one element selected from the group consisting of Cu and Mg and from 0.1% to 1% by weight of at least one element selected from the group consisting of Cr and Mn are further contained.

5. An aluminum-base alloy bearing according to claim 1, wherein said hard element is from 0.5% to less than 5% of silicon, and from 1% to 35% by weight of tin is further contained.

6. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin and from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth are further contained and said hard element is from 0.5% to less than 5% of silicon.

7. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin, and from 0.1% to 2.0% by weight of at least one element selected from the group consisting of copper and magnesium, are further contained and said hard element is from 0.5% to less than 5% of silicon.

8. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin, from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth, and from 0.1% to 2.0% of at least one element selected from the group consisting of copper and magnesium, are further contained, and said hard element is from 0.5% to less than 5% of silicon.

9. An aluminum-base alloy bearing according to one of claims 5 through 8, wherein the tin content is from 5% to 25% and the silicon content is from 2% to less than 5%.

10. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is further contained and said hard element is from 0.5% to less than 5% of silicon.

11. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth and from 0.1% to 2.0% by weight of at least one element selected from the group consisting of copper and magnesium are further contained and said hard element is from 0.5% to less than 5% of silicon.

12. An aluminum-base alloy bearing according to claim 10 or 11, wherein the content of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is from 1% to 6% and the silicon content is not less than 2%.

13. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin is contained and said hard element is from 5% to 11% of silicon.

14. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin and from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth are further contained and said hard element is from 5% to 11% of silicon.

15. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin and from 0.1% to 2.0% by weight of at least one element reflected from the group consisting of Cu and Mg are further contained and said hard element is from 5% to 11% of silicon.

16. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin and 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth, and from 0.1% to 2% of at least one element selected from the group consisting of copper and magnesium are further contained and said hard element is from 5% to 11% of silicon.

17. An aluminum-base alloy bearing according to one of claims 14 through 16, wherein the content of tin is from 3% to 20% and the content of silicon is from 5% to 11%.

18. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% by weight of

at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is further contained and said hard element is from 5% to 11% of silicon.

19. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth and from 0.1% to 2.0% by weight of at least one element selected from the group consisting of copper and magnesium are further contained and said hard element is from 5% to 11% of silicon.

20. An aluminum-base alloy bearing according to claim 18 or 19, wherein the content of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is from 1% to 6% and the silicon content is from 5% to 9%.

21. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin is further contained and said hard element is from 0.5% to 11% by weight of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

22. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% of tin, from 0.1% to 10% by weight of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is further contained and said hard element is from 0.5% to 11% of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

23. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% by weight of tin, and from 0.1 to 2.0% by weight of at least one element selected from the group consisting of Cu and Mg is contained and said hard element is from 0.5% to 11% of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

24. An aluminum-base alloy bearing according to claim 1, wherein from 1% to 35% of copper, from 0.1% to 10% of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth, and from 0.1% to 2.0% of at least one element selected from the group consisting of copper and magnesium are contained and said hard element is from 0.5% to 11% of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

25. An aluminum-base alloy bearing according to one of claims 21 through 24, wherein the content of tin is from 3% to 20% and the content of said hard element is from 1% to 9%.

26. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth is contained and said hard element is from 0.5% to 11% of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

27. An aluminum-base alloy bearing according to claim 1, wherein from 0.1% to 10% of at least one element selected from the group consisting of lead, cadmium, indium, thallium, and bismuth and from 0.1% to 2.0% of at least one element selected from the group consisting of copper and magnesium are contained and said hard element is from 0.5% to 11% of at least one element selected from the group consisting of manganese, iron, molybdenum, nickel, zirconium, cobalt, titanium, antimony, chromium, and niobium.

28. An aluminum-base alloy bearing according to any one of claims 1 through 27, wherein hard particles not less than 10 microns and not more than 40 microns in size are present not less than two per 3.56×10^{-2} mm^2 in an optical part of the alloy.

29. An aluminum-base alloy bearing according to claim 28, wherein hard particles not less than 10 microns and not more than 40 microns in size are present not less than five per 3.56×10^{-2} mm^2 in an optional part of the alloy.

30. An aluminum-base alloy bearing according to any one of claims 13 through 20, wherein hard particles less than 17 microns but not more than 40 microns, preferably not less than 20 microns and not more than 40 microns in size, are present not less than two per 3.56×10^{-2} mm^2 in an optional part of the alloy.

31. An aluminum-base alloy bearing according to one of claims 2 through 12, wherein hard particles not less than 20 microns and not more than 40 microns in size are present not less than two per 3.56×10^{-2} mm^2 in an optional part of the alloy.

32. An aluminum-base alloy bearing according to one of claims 1 through 27, wherein hard particles not less than 20 microns and not more than 40 microns in size are present not less than five per 3.56×10^{-2} mm^2 in an optional part of the alloy.

33. An aluminum-base alloy bearing according to one of claims 1 through 27, wherein from 0.1% to 1% by weight of at least one element selected from the group consisting of Cr and Mn, is further contained.

34. An aluminum-base alloy bearing according to one of claims 1 through 27, wherein a shaft, which is the opposed member of the bearing, is nodular graphite cast iron or flake graphite cast iron.

35. An aluminum-base alloy bearing according to one of claims 1 through 27, wherein said hard particles are nodular as seen in a horizontal plane, i.e. in a plane parallel to a plane to be in contact with

an opposed member, preferably as seen in the horizontal plane and a plane vertical to it.

36. An aluminum-base alloy bearing according to one of claims 1 through 35, wherein said aluminum alloy is bonded to a backing metal.

37. An aluminum-base alloy bearing according to one of claims 1 through 35, wherein the remainder of the aluminum alloy consists of aluminum and unavoidable impurities.

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